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Effects of transportation and development on black bear movement, mortality, and use of the Highway 93 corridor in NW Montana

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Effects of Transportation and Development On Black Bear Movement, Mortality, and Use of the Highway 93 Corridor in NW Montana

By

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Chairperson: Dr. Christopher W. Servheen

ABSTRACT

I conducted a study along the U.S. Highway 93 transportation corridor to facilitate future assessments of the efficacy of planned wildlife passages and the effects of increases in traffic and development on resident black bears (*Ursus americanus*). I conducted DNA sampling and used hourly location data from GPS collars on black bears (n = 18) to provide information on movement, mortality patterns, use of the highway corridor, and genetic variability prior to highway expansion and incorporation of wildlife passages. Crossing was more likely 1) by adult females and subadult males; 2) by food-conditioned bears; 3) in microhabitats with streams, cover, and human development; 4) near roadkill clusters; and 5) near planned wildlife passages. I also found evidence that highways and associated development influenced corridor use patterns by attracting food-conditioned bears and repelling wary bears in certain circumstances. Temporal analyses suggested crossings occurred mostly at night when traffic volumes are lowest, even though these hours exhibited the lowest mean daily movement rates. However, bears moved at higher speeds when crossing highways than during the same hours when they were not crossing, indicating disturbance regardless of traffic volumes. These results suggest that this transportation corridor was a partial barrier to wary bears, demonstrated by their reluctance to cross highways or to use areas near highways. In contrast, highways were fully permeable to food-conditioned bears, which crossed frequently and used areas near highways greater than expected. Food-conditioned bears, however, have a higher risk of mortality due to an increased likelihood of management removal or vehicle collision. Future assessment of the efficacy of wildlife passages should focus on wary bears, as they are less likely to be killed through management removal or vehicle collision, and therefore more likely to reproduce and contribute to gene flow across highway corridors. This study suggests that while black bears may cross near planned wildlife passages, the absence of adequate linkage habitat or presence of development near passages could compromise connectivity by either deterring wary bears from using passages or by increasing the likelihood of management removals if bears funneled towards anthropogenic food sources become food-conditioned.

ACKNOWLEDGEMENTS

I give special thanks to Western Transportation Institute (WTI), which provided funding for this project. Amanda Hardy and Marcel Huijser at WTI also graciously provided additional support in the form of traffic counters and expertise. I am also grateful to all of the other entities that provided cooperation or support in various ways, including: U.S. Fish and Wildlife Service, Montana Department of Transportation, Federal Highways, the Confederated Salish and Kootenai Tribes, Montana Fish, Wildlife and Parks, and the University of Montana. The success of this project was made possible through the encouragement, assistance, and support of many individuals. First and foremost, I thank my advisor, Dr. Christopher Servheen, for the opportunity to fulfill my dream of studying forest carnivores using GPS and GIS technology, as well as for continual guidance throughout all aspects of study design, implementation, and analysis.

This success of this project would not have been possible without the guidance of the faculty at the University of Montana. My sincerest appreciation goes to my committee members, Dr. Rick Mace, Dr. Kerry Foresman, and Dr. Dave Naugle, for their thoughtful critiques of my study design and final analyses. Many thanks to Dr. Brian Steele and Dr. Jon Graham for their endless patience and perseverance in educating me in the art of statistics and for helping me work through the nuances of several complex analyses. Dr. Hans Zuuring took the time to help me out during the chaos prior to finals week, and graciously shared his methods for conducting particular statistical analyses. Roly Redmond's Spatial Analysis Lab either directly provided GIS data or pointed me towards where I could find what I was seeking. I am also grateful to all the other professors who shared their knowledge through the excellence of their classrooms, including Dr. Fred Allendorf, Dr. Lisa Eby, and Dr. Scott Mills. Finally, I would like to give a sincere word of praise to Jeanne Franz, who is the backbone of our department and who truly has the answers to all life's important questions (or at least the really important ones, like how to graduate!).

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I:

Introduction and Background

THESIS PURPOSE AND OBJECTIVES

The purpose of my thesis research was to study bear-highway interactions prior to expanding Highway 93 to 4 lanes and incorporating wildlife passages into the highway design. Conducting analyses pre-construction will facilitate post-construction assessments of the efficacy of wildlife passages and the effects of increasing traffic and development on resident black bear. My objectives were to: evaluate pre-construction crossing behavior, mortality patterns, and corridor permeability; assess the possible existence of a habitat disturbance zone near the highway and associated developments; estimate a minimum black bear density within the transportation corridor; and archive baselines of genetic variability within this black bear population. My research will enable managers to better understand current bear-highway interactions and to evaluate future ecological, behavioral, and demographic changes that may result from alterations of highway design, traffic volume, and development intensity. Specific objectives and methods to accomplish these goals can be found in individual chapters.

I have organized my analyses into three chapters: Chapter I is a literature review. Chapters II and III contain results of analyses, and have been formatted for submission to journals. Chapter II contains analyses highway permeability, crossing behavior, and mortality patterns. Chapter III contains investigations of how the highway corridor may influence how different classes of bear use the Highway 93 transportation corridor. I summarize the results of genetic analyses in Appendix A.

REVIEW OF RELEVANT LITERATURE

Background

Black bear (*Ursus americanus*), classified as a game species in most states, historically experienced severe declines across much of the United States due to over-exploitation, habitat loss and habitat fragmentation (Miller 1990). While most populations of black bear in the U.S. are currently stable or increasing, they are classified in seven states as threatened or endangered, and habitat loss and fragmentation continue to threaten the species in most of the 35 states where they occur (Pelton et al. 1999). When populations become small and isolated they are more susceptible to stochastic environmental, genetic, and demographic changes (Gilpin and Soule 1986). Management protocols for bears must emphasize connectivity among populations to enable gene flow and avoid reduced fitness due to inbreeding effects (Couvet 2002). While a decrease in persecution and the enactment of conservation strategies for black bear limit mortality, low reproductive rates will make populations slow to recover if increasing levels of habitat loss and fragmentation induce future declines (Miller 1990). In the Northern Rockies, linkage between large blocks of habitat is considered vital for the persistence of large carnivores (Servheen et al. 2001).

Habitat Fragmentation by Highways

An estimated one-fifth of the land area of the U.S. is ecologically affected by public road systems (Forman 2000). Habitat fragmentation can be caused by a number of different factors, including increased human activity such as hunting, hiking, and snowmobiling; and habitat loss through activities such as logging, commercial and residential development, and construction of highways and forest roads. Biologists and the conservation community have been concerned about the effects of roads on the distribution, behavior, and movements of many different species for the last several decades (Garland and Bradley 1984, Belden and Hagedorn 1993, Evink et al.

1996, Forman and Alexander 1998). Because human developments tend to follow transportation corridors along valley floors, the degree and effect of habitat fragmentation depends on both the intensity and distribution of development (Servheen et al. 2001, Figure 1.1). Highways have both direct and indirect effects on bear populations. Directly, they cause mortalities as animals attempt to disperse or access habitat areas adjacent to the highway, and indirectly, they can cause avoidance of habitats which reduces habitat availability. In response to these issues, USFWS has begun to identify linkage habitat across highways (Servheen et al. 2001, Figure 1.2), and the Department of Transportation has begun to incorporate wildlife passages into highway designs (Figure 1.3). The area north of Evaro along Highway 93 has been identified as an important linkage zone (Mietz 1994) under similar protocols to those used by Servheen et al. (2001). Highway 93, including the section traversing this linkage zone, is undergoing reconstruction that will include incorporation of 26 wildlife passages between Evaro Hill and St. Ignatius.

Highway Mortalities

The number of black bears killed on U.S. highways varies by state from 0 to 70, with an average of 400 bears/year nationally (Pelton et al. 1999). Wooding and Maddrey (1994) reported a larger range of 0-200 black bears killed/year/state between 1989 and 1993. Several studies have used mortality locations to infer characteristics of highway crossing by various species, including white-tailed deer (Finder et al. 1999), mule-deer (Romin and Bissonette 1996), small vertebrates and avian species (Clevenger et al. 2003), grizzly bear (Huber et al. 1998, Kaczensky 2003), and black bear (Wooding and Brady 1987, Wooding and Maddrey 1994, Gilbert and Wooding 1996, McGown and Eason 2001, Hebblewhite 2002). Subadult male black bears are killed most frequently and males are impacted more than females (Wooding and Brady 1987, Huber et al. 1998, Kaczensky 2003). Black bear roadkills are concentrated along sections of a highway associated with forests, wetlands and drainages (Wooding and Brady 1987). Although placement of wildlife passages is often based on roadkill locations, crossings occur over a much larger extent of highway than indicated by mortalities (McGown and Eason 2001). Therefore, understanding differences in spatial distributions of mortality and crossing locations is important for mitigating barrier effects of highways.

High bear mortality has been documented on Highway 93 through the Flathead Indian Reservation. I evaluated the spatial distribution and micro-habitat characteristics of mortality locations and compared these results to crossing characteristics. To my knowledge, no previous comparative analyses have been undertaken to assess spatial differences between black bear crossing and mortality locations.

Highway versus Forest Road Permeability and Crossing Characteristics

Highways and unpaved forest roads have disparate effects on wildlife movement and habitat use due to differences in levels of human disturbance. Mortalities and reduced use of areas adjacent to unpaved roads are primarily a result of hunting, poaching, and avoidance of human access areas. In contrast, mortalities and reduced use of areas adjacent to highways is a result of high-speed collisions, the removal of nuisance bears from human development sites, and avoidance of disturbance associated with traffic, development, and intense human activity. Unfortunately, highways and forest roads are often simply referred to as "roads" without specificity, which often makes results appear contrary and difficult to interpret. I define "unpaved road" as any forest road regardless of its accessibility or specific surface substrate, while highways will be referenced as such.

Black bear avoidance of highways, defined by non-crossing behavior, increases with highway density in home ranges (Beringer 1990). In contrast, crossing of unpaved roads increases with road density in home ranges (Beringer 1990). However, black bears may avoid unpaved roads by selecting home ranges with lower road densities (Brody and Pelton 1989). Beringer et al. (1990) found that most crossings of unpaved roads (identified with 1-2 VHF locations/day) occurred during daylight hours. Car and Pelton (1984) found that crossings occurred most in summer when bears were most active. In contrast, Brandenburg (1996) found that highway crossing by black bear occurred nocturnally and coincides with low traffic volumes. Brody and Pelton (1989) did not detect differences in crossing frequency of unpaved roads by black bears of any age-sex class during any season. McGown and Eason (2001) used 1-3 locations per week to identify crossing locations, and also found no differences in crossing frequency of highways by of any sex, but did find that more crossings occurred in fall than spring. Some studies have found that black bears cross highways less frequently than unpaved roads (Brody and Pelton 1989, Beringer et al. 1990), while others report they cross highways frequently (McGown and Eason 2001). While little is known about micro-site characteristics at crossings, McGown and Eason (2001) indicated that black bears in Ocala National Forest, Florida, crossed more often than expected by chance in open, young age stands.

More recent and comprehensive information is available for grizzly bear highway crossing activity, largely because use of GPS collar technology has allowed collection of highly accurate data with short and consistent time intervals between locations. While spatial and temporal characteristics of grizzly bear crossing activity may differ from that of black bear, they give an indication of what variables may be important to consider in black bear analyses. Grizzly bears cross highways more at night than during the day (Waller and Servheen 2005, T. Graves, unpublished data, University of Montana, Missoula, MT, USA); when or where traffic volume is lowest; in areas with higher terrain ruggedness; in grassland or deciduous areas; and closer to cover, stream crossings, and high-quality habitat (Gibeau et al. 2001, Chruszcz et al. 2003, Waller and Servheen 2005). Chruszcz et al. (2003) found no effects of sex or season on crossing of high volume highways, but that female grizzly bears cross low-volume highways more frequently than males regardless of season. In contrast, Waller and Servheen (2005) found that adult females crossed the least of any age-sex group, and subadult males crossed most. No data is currently available to assess the effects of food-conditioning on crossing behavior, but Chruszcz et al. (2003) found no differences in crossing between habituated and wary bears during any season.

Understanding where, when, and how bears cross highways, prior to the incorporation of wildlife passages and highway fencing, will help managers with future assessments of the efficacy these mitigation measures. Because the efficacy of wildlife passages may be influenced by their location, frequency, and accessibility, I was interested in evaluating pre-construction patterns associated with highway crossings by black bear, and comparing this data to the location and distribution of planned wildlife passages. I used hourly GPS collar location data to identify locations and temporal patterns of crossings, and used crossing location data to evaluate the spatial distribution and micro-habitat characteristics of crossing locations.

Habitat and Highway Corridor Use Relative to Highways and Unpaved Roads

Highways have been shown to affect ecological processes in areas up to 1000 m from roadsides (Forman and Deblinger 2000). However, current knowledge of home range placement and habitat use by black bears in relation to unpaved roads and highways is incomplete and somewhat contradictory (Beringer et al. 1990). Confusion is partly due to a lack of differentiation between highways and unpaved roads, as well as temporal biases resulting from limited acquisition of nighttime locations. Carr and Pelton (1984) found that black bears cross unpaved roads often, and frequent habitats near unpaved roads. In contrast, Kasworm and Manley (1990), using daytime VHF radio location data, found that black bear: 1) use habitats within 274 m of unpaved open roads less than expected in the spring and areas <914 m less than expected in the fall; 2) males used all areas (<1128 m) as expected; 3) females selected against areas <914 m from roads and selected for areas 1,860 to 3,322 m from roads; and 4) locations occurred within <2km of unpaved roads 58% of the time. A review by Wooding and Maddrey (1994) notes that black bear avoidance of roads (unspecified type) has ranged from 274 to 720 m. Other studies have found that black bears may use low-traffic unpaved forest roads frequently as travel lanes (Beringer 1990), but in areas that allow hunting, this has a cost. Beringer (1990) states that while black bears did not frequently cross a highway, they were located nearby, often approaching and then moving either away from or parallel to it. McGown and Eason (2001) found no evidence that black bears infrequently crossed a highway or that they avoided habitats adjacent to a highway. However, other studies report that highways often delineate home range boundaries, which has been attributed to avoidance behavior (Brody and Pelton 1989, Beringer 1990).

More studies of habitat use near unpaved roads and highways have been conducted for grizzly bear, and have consistently demonstrated the existence of disturbance zones, especially at higher traffic volumes, around unpaved roads and highways. All of these studies except Waller and Servheen (2005) used VHF radio telemetry locations to infer response. Several studies have found that grizzly bear: avoid areas near unpaved roads within a range from 100 m in spring to 914 m in fall; yearlings use and males avoid areas near roads; females are willing to use areas that adult males avoid; and selection of areas near unpaved roads is independent of traffic volumes (Mattson 1987, McLellan and Shackleton 1988, Wielgus et al. 2002). In contrast, Mace et al. (1996) found that grizzly bears used areas near unpaved roads greater than or equal to expected when traffic was less than 10 vehicles per day, but avoided them at greater traffic volumes; that they used areas with higher unpaved road densities more in the spring than other seasons; and they avoided areas with higher unpaved road densities in lower elevation habitats. Highway avoidance by grizzly bears has also appeared to depend on traffic volumes and levels of human disturbance. Mattson (1987) found that avoidance of paved primary roads (roughly equivalent to highways given the high traffic volumes in summer months) in Yellowstone National Park extends from 500 m in the spring and summer to 3 km in the fall, but that foraging behavior was generally disrupted over a much larger range. Waller and Servheen (2005) also found grizzly bears avoided areas within 500 m of highways. Chruscz et al. (2003) found that grizzly bear, regardless of sex or habituation, used areas adjacent to low-volume highways more than expected, but also that they used these areas more than areas near high-volume highways. Chruscz et al (2003) also found that females were farther from low-volume highways than males, and that wary males and females were farther from low-volume and high-volume highways than habituated males and females, respectively and collectively.

Because highway improvement projects are often associated with increases in traffic and development, I was interested in evaluating how current levels of disturbance near the highway may influence placement and use of home ranges. Knowledge of disturbance associated with the highway prior to highway improvement will help managers better assess the relative effects of any increases in traffic or development that may occur in the future. I evaluated differences between age-sex and habituation classes of black bears with regard to home range proximity to highways and the spatial utilization of areas adjacent to highways.

The Role of GPS Technology in Advancing Scientific Understanding

Previous sampling constraints and location errors associated with VHF telemetry have limited assessment of crossing frequencies and locations. Identification of highway crossing locations and frequencies by black bears has been based on low-resolution data, as telemetry acquisition rates ranged from once per day to once per week. Assessment of how black bears use areas adjacent to highway has been limited due to unequal sampling intervals and diurnally-biased location data. I am only aware of three studies, all focusing on grizzly bear, that have used GPS technology or sub-daily data to evaluate the influence of various spatial and temporal characteristics on highway crossing behavior or use of areas adjacent to highways (Chruscz et al. 2003, Waller and Servheen 2005, T. Graves, unpublished data, University of Montana, Missoula, MT, USA). To my knowledge, no previous studies have been published that use GPS collars and hourly data to measure factors affecting black bear highway crossing behavior and movements in relation to highways. This type of high-resolution data has not been previously available for black bears because weight limitations did not allow deployment of GPS collars on this smaller species of bear. Recent technological innovations, however, allowed me to use GPS collars on black bears to evaluate use of areas near highways as well as to assess the spatial distribution, temporal patterns, and micro-site characteristics of highway crossings. To my knowledge, this is also the first study to assess these patterns pre-wildlife passage construction.

The Role of Genetics in Assessing Habitat Connectivity

Non-invasive DNA sampling using hair collection stations has recently become an increasingly popular method to estimate population size with mark-recapture techniques (Woods et al. 1999, Mowat and Strobeck 2000, Boulanger 2002). It has also been used with measures of genetic variation to estimate levels of connectivity in fragmented landscapes (Marshall and Ritland 2002); and with genetic assignment tests to measure gene flow between populations (Waser and Strobeck 1998, Waser et al. 2001). More recently, as the effects of transportation and development on wide-ranging species have become of greater concern, genetic variation has been used to measure connectivity across barriers such as highway corridors (Proctor 2003, Thompson et al. 2005). DNA sampling is a promising technique for measuring connectivity across highways because it allows: the estimation of population size or density for comparison to other demographic trends; measurement of connectivity indirectly through genetic assignment testing or directly when individuals are captured on both sides of a highway; and the establishment of genetic baselines for future evaluation of quantifiable changes in connectivity across highways. I employed DNA sampling to estimate a minimum density of black bears within the highway corridor and to record pre-construction genetic variability that will allow detection of any future changes in variation and gene flow across the transportation corridor.

STUDY AREA DESCRIPTION

My study area is located on and adjacent to the Flathead Indian Reservation, Montana, which is home to the Confederated Salish and Kootenai Tribes (CSKT). Highway 93 extends north-south through the Reservation, and consists of four lanes up to the southern boundary of the Reservation at the town of Evaro, where it becomes a two-lane highway that has recently incurred a dramatic increase in traffic volumes and development. Montana Department of Transportation (MDOT) has documented high traffic volumes of approximately 8030 vehicles/day in the Evaro area and 6800 vehicles/day in the Ravalli area. In response, MDOT is expanding most of Highway 93 between Evaro Hill and Polson by widening the highway into three or four lanes. This expansion will include installation of 42 wildlife crossing structures capable of providing passage to a variety of species, as well as fencing to direct animals to these structures (MDOT 2000).

The study area is located on the southwestern edge of the Northern Continental Divide Ecosystem (U.S. Fish and Wildlife Service 1993), and encompasses the section of Highway 93 that stretches from Evaro Hill (just north of the I-90 junction) to St. Ignatius. It also includes a section of State Route 200 located directly west of Ravalli Junction. Most trapping, collaring, and monitoring occurred in two primary linkage areas that serve as habitat connections which facilitate wildlife movement and maintain connectivity between the Northern Continental Divide Ecosystem to the northeast and the Salmon-Selway Ecosystem to the southwest (Mietz 1994, Servheen et al. 2001). The Evaro area is located along the southernmost section of the proposed highway improvement on the Reservation, from the town of Evaro north towards the town of Arlee (Figure 1.4). Specifically, it includes the highway segment from the Reservation Boundary to Agency Creek, which is approximately 12 km. The Ravalli area begins at Spring Creek and continues NE of Ravalli Junction to Sabine Creek, just south of St. Ignatius, and includes approximately 14 km of Highway 93 and 4.5 km of Highway 200. The Highway 93 corridor is between the Ninemile Mountains to the west and the Rattlesnake Wilderness Area and Jocko Primitive Area to the east. To the north and northeast are the National Bison Range and the Mission Mountains. These areas are primarily within the boundaries of the Flathead Indian Reservation and are characterized by a mixture of private, tribal, federal (the National Bison Range), and state lands.

The two focus areas of this study differ substantially in land ownership, land use, and habitat. The Evaro area is approximately 69% tribal, 15% private land, 1% state, while the Ravalli area is approximately 20% tribal, 62% private, 16% federal (National Bison Range), and 2% State. Development is concentrated near the highway in both areas. Forest cover is predominantly coniferous but deciduous trees are found along rivers, streams, irrigation ditches, and ponds. Each area contains some forest habitat adjacent to the highway, but the Evaro area consists of approximately 77% forest cover, while the Ravalli area consists of only 25% forest cover.

Topographically, the highway corridor through the Ravalli area has more precipitous slopes than the Evaro area and is dominated by large open hillsides of Palouse Prairie grasslands. Scree and shrub fields, agricultural lands, and forest patches comprise the remaining habitats. The Evaro area is characterized by fairly continuous forest habitat on surrounding slopes with few dispersed agricultural lands in the valley bottom. Native berries and fruit from small orchards are also common in both areas and can comprise a significant portion of bear diets in this region (Servheen 1983). Both areas have cattle grazing allotments and have been logged extensively, and so contain a substantial number of forest roads. The Jocko River and a railway parallel Highway 93 and Highway 200 in the Ravalli area, while Finely and O'Keefe Creeks as well as the same railway parallel much of Highway 93 in the Evaro area. The two areas are separated by approximately 13 km of a wide valley composed of agricultural lands and development interspersed with sparse deciduous forest and shrub cover along riparian areas (Figure 1.1). Elevation varies from 1000-2250 m in the Evaro area and from 825-1500 m in the Ravalli area. Rise in elevation is much greater in the adjacent Mission Mountains and Rattlesnake Wilderness to the east.

FIGURES

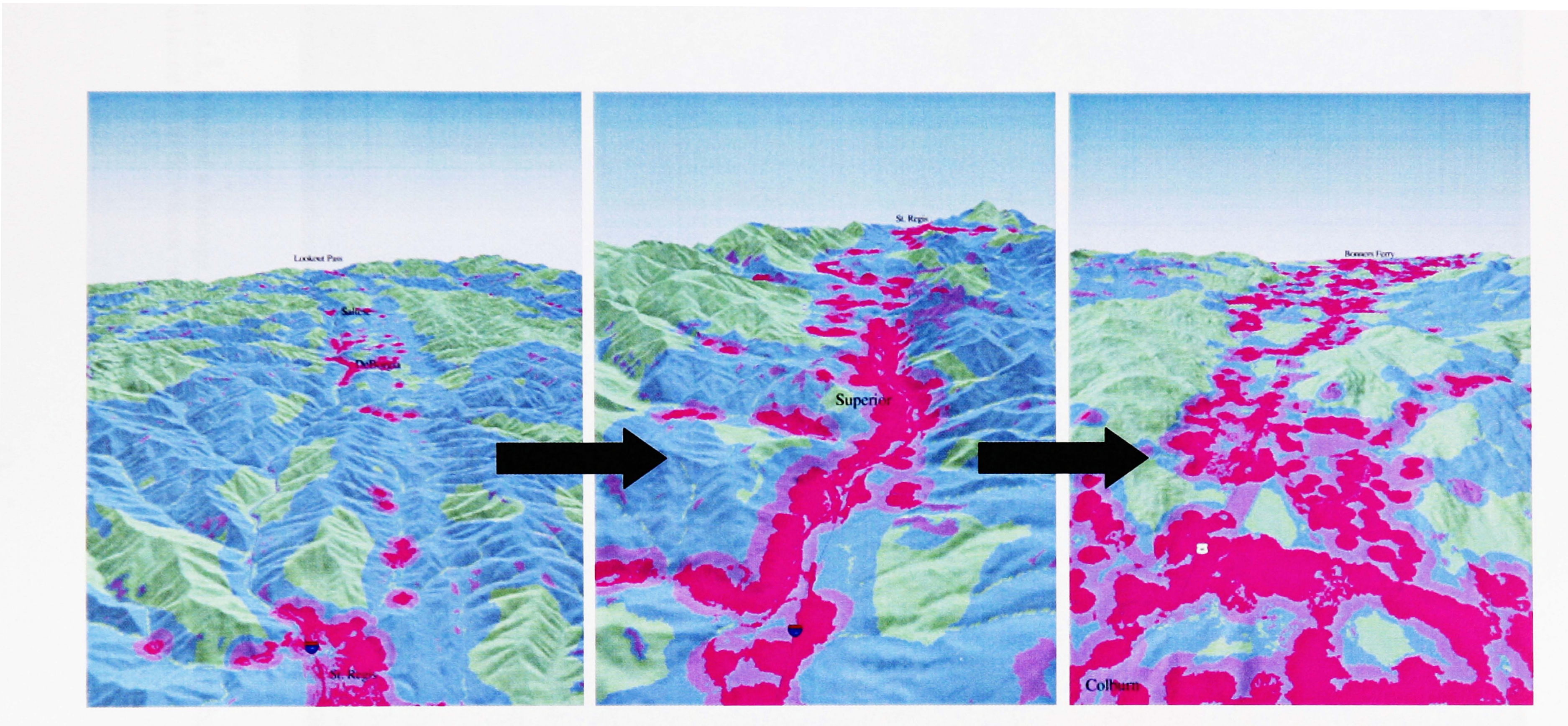

Figure 1.1. The highway corridor on the left illustrates a transportation system in Montana with little human impact (pink) and ample linkage areas with low (blue) or minimal (green) human impact. The next two images illustrate the decrease in available linkage areas that occurs with increasing human impact. Figures reproduced from Servheen et al. (2001).

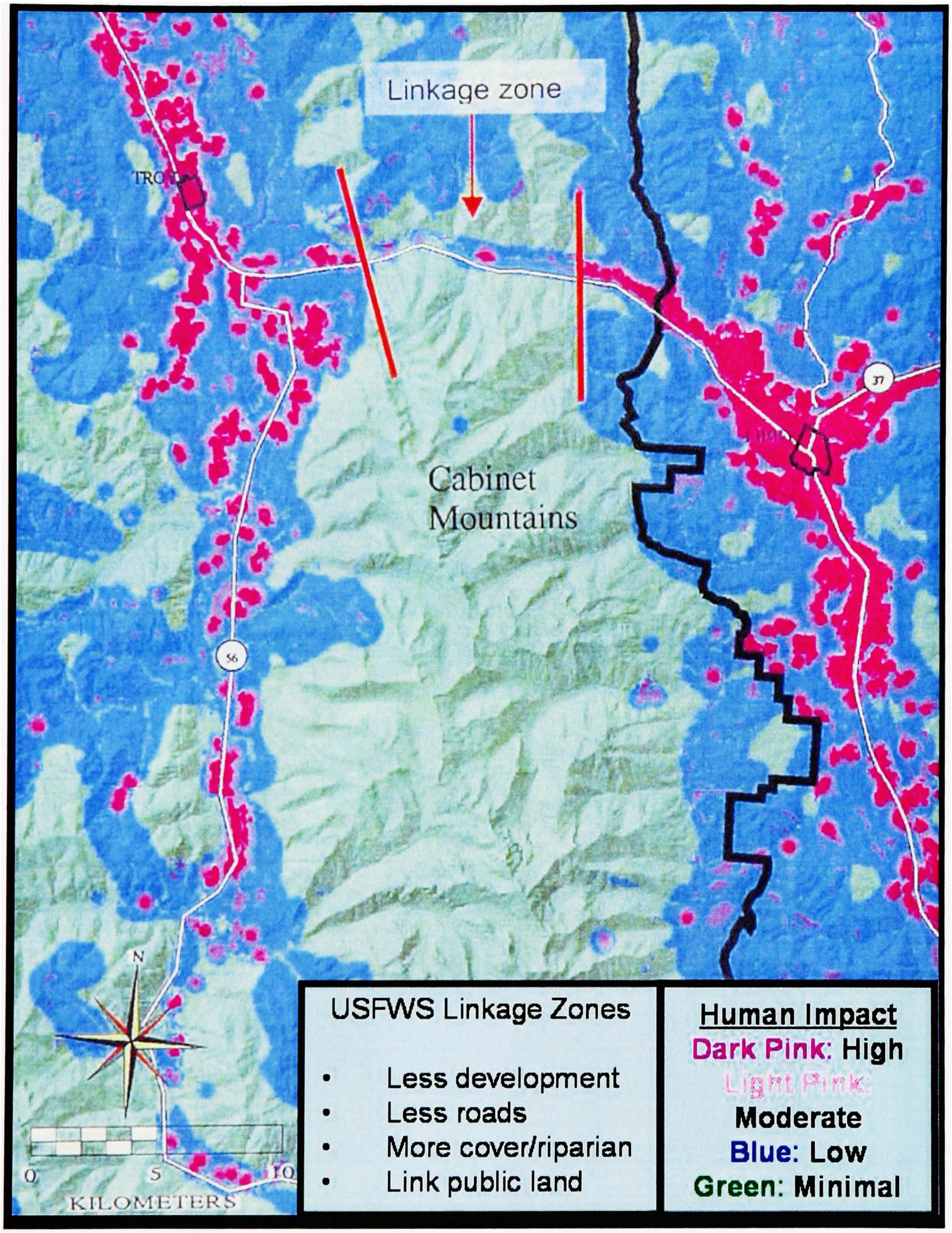

Figure 1.2. Map of a linkage zone identified near Libby, Montana. Figures modified and reproduced from Servheen et al. (2001).

Figure 1.3. Images of wildlife passages in the form of box culvert underpasses (left), overpasses (right), and span bridges (center). Images by U.S. Department of Transportation, Federal Highways Administration (http://www.fhwa.dot.gov/environment/wildlifecrossings).

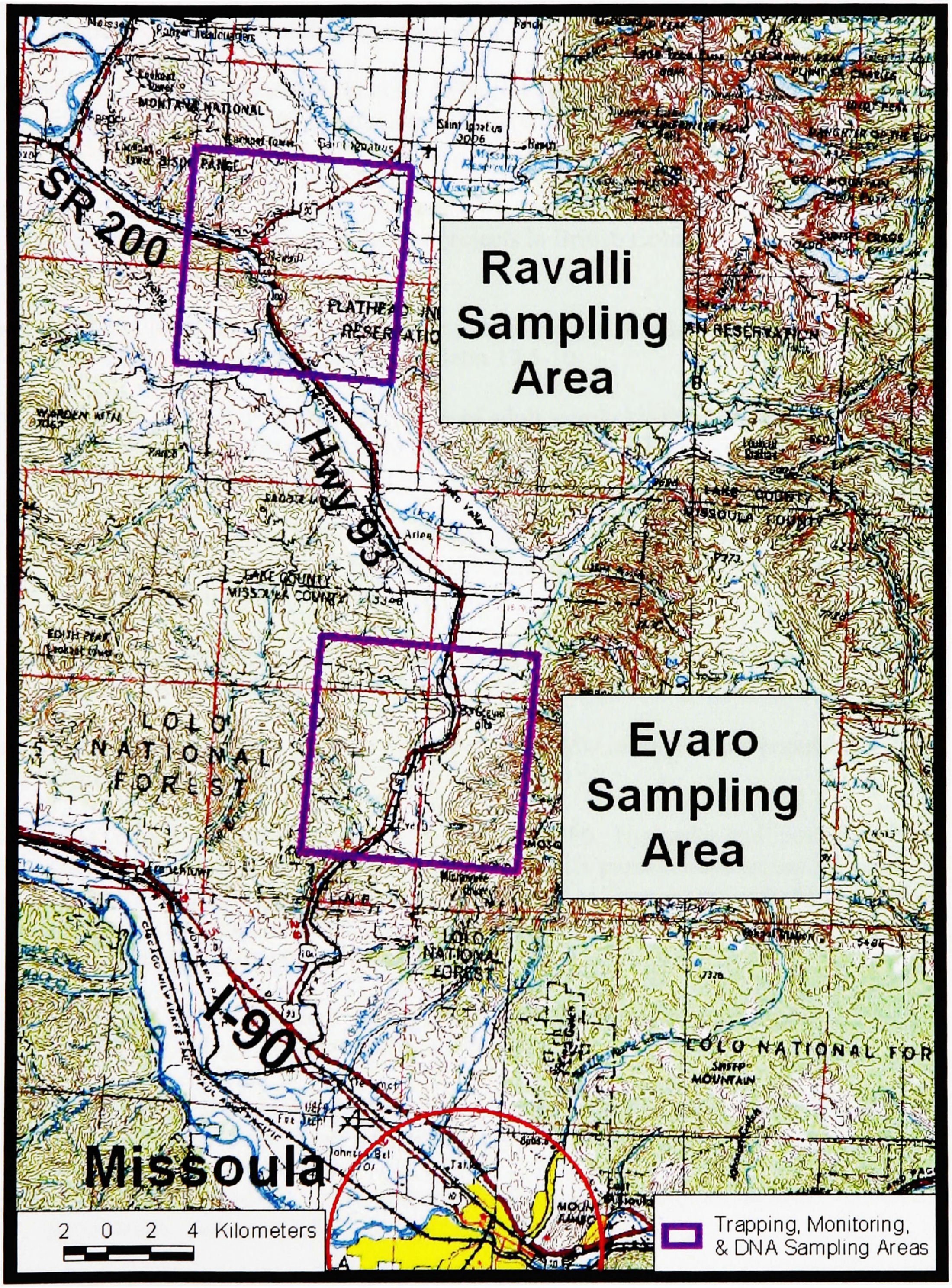

Figure 1.4. Map of study area along the Highway 93 transportation corridor on the Flathead Indian Reservation, northwest of Missoula, MT.

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CHAPTER II:

Analysis of Highway Crossings and Mortality Patterns of Black Bear: Implications for Wildlife Passage Planning

ABSTRACT

Our understanding of the effects of highways on wildlife and the efficacy of wildlife passages has been limited due to a paucity of pre- and post-construction data of detailed movement and mortality patterns within transportation corridors. Prior to highway construction and inclusion of wildlife passages along a high-traffic highway, I used hourly locations from GPS collars to: analyze spatial and temporal characteristics of crossing locations and variation in crossing frequency among classes of black bear; compare hourly crossing frequencies to hourly traffic volumes and crossing speeds to average speeds by time of day; and assess the spatial distribution and proximity of crossings and roadkills to planned locations of wildlife passages. Results indicate that food-conditioned bears crossed the highway more than non food-conditioned bears, adult females and subadult males crossed highways more frequently than adult males, and subadult males are less discerning about when to cross highways. Bears were more likely to cross highways: at night; near stream intersections and areas with higher stream density; closer to cover when in open habitat areas; where there is a higher percentage of cover within 200 m when in open habitat areas; and near human development. Crossing activity was highest at the time of day when movement rates were lowest, and was negatively correlated with traffic volume. Speed of movement during crossings was higher than during non-crossing times. Crossings and roadkills were clustered and relatively near planned locations of wildlife passages, but high levels of development may limit accessibility to some passages. Highways appeared to be a partial barrier to non food-conditioned bears, which crossed them seldom or not at all, but were fully permeable to food-conditioned bears, which crossed frequently. However, food-conditioned bears are not likely to substantially contribute to gene flow across highways due to their high probably of succumbing to management removal. Identifying locations to place wildlife passages should therefore emphasize providing access for non food-conditioned bears. This study suggests that while black bears may cross near planned wildlife passages, the absence of adequate linkage habitat or presence of development near passages could potentially compromise connectivity by either deterring wary bears from using passages or increasing the likelihood of management removal if bears funneled towards anthropogenic food sources become food-conditioned.

INTRODUCTION

Public roads impact ecological systems on over one-fifth of the land area of the United States (Forman 2000). Roads and associated development decrease effective habitat (Mattson 1990) and reduce connectivity when wildlife avoids the disturbance and human presence commonly associated with transportation systems or when mortalities result from crossing attempts (Wooding and Maddrey 1994). High traffic volumes and human disturbance increases the likelihood that highways will act as barriers to wildlife (Servheen et al. 1998). Wildlife mortalities that occur on major transportation systems cause concern for both bear population viability and human safety. If highway permeability is reduced below threshold levels of 1-10 migrants per generation (Mills 1996, Couvet 2002), these highways can then produce barrier effects and populations can become small, isolated, and more vulnerable to the deleterious effects of inbreeding and stochastic events (Gilpin and Soule 1986, Servheen and Sandstrom 1993, Land 1994). Barrier effects can be particularly important for wide-ranging species, such as black bear (*Ursus americanus*) and grizzly bear (*Ursus arctos*), which are more likely to encounter highways and associated zones of human influence (Mattson 1990).

The scientific community has long been concerned about the negative ecological effects of roads (Evink et al. 1996, Forman and Alexander 1998, Forman 2000). This concern has extended to black bear (Carr and Pelton 1984, Wooding and Brady 1987, Brody and Pelton 1989, Beringer et al. 1990, Wooding and Maddrey 1994, Gilbert and Wooding 1996, McGown and Eason 2001) and grizzly bear (Mattson 1987, Servheen and Sandstrom 1993, Chruszcz et al. 2003, Kaczensky et al. 2003, Waller and Servheen 2005). In the 1970's, transportation agencies began to incorporate fencing and wildlife passages, such as overpasses, open-span bridges, and box culvert underpasses, into highway designs to better mitigate public safety and ecological concerns (Clevenger and Waltho 2000). While some research has focused on assessing the efficacy of these passages, (Romin and Bissonette 1996, Clevenger and Waltho 2000, Clevenger and Waltho 2005), pre-construction data was unavailable for these studies, and therefore, conclusions have been limited to post-hoc evaluations of passage use. Pre-construction data is vital for more fully understanding the effectiveness of wildlife passages and the effects of changing transportation characteristics on movement patterns and permeability. Previous pre-construction/post-construction studies that have been undertaken (Smith and Dodd 2003, Dodd et al. 2003, Thompson 2005) have used roadkill data or genetics to assess highway permeability. No information is available that uses detailed movement data from GPS collars to assess the effects of highways on movement, permeability, and crossing behavior of black bear.

Expansion plans for the Evaro to Polson section of Highway 93 in NW Montana are underway and 42 crossing structures will be incorporated into the design. Traffic volumes on this highway are expected to almost double by the year 2024 (MDOT 2000). If crossing structures do not provide safe passage, increased traffic volumes could pose a threat to bear movement. Preconstruction data is vital for assessing effectiveness of crossing structures once they are in place. Previous knowledge of highway permeability to black bears has been limited by sampling constraints (acquisition rates ranging from once per day to once per week, with occasional 24 hour monitoring) and location errors associated with VHF telemetry. My study is the first to employ GPS technology to understand highway crossing behavior of black bear, and also the first to make direct comparisons of crossing frequencies to traffic volumes during actual crossing times. Finally, I am able to provide an understanding of the influence of food-conditioning on behavior of black bears during highway crossings.

The purpose of my study was to provide information on black bear movement in relation to transportation and development before commencement of highway improvement activities, to provide a mechanism by which to gauge effects of increases in traffic and development and assess the efficacy of planned wildlife passages. A better understanding of when, where, and how bears cross highways, and what factors influence this behavior, is of critical importance to allow managers to develop methods to adequately maintain connectivity. My specific objectives were to: assess current highway permeability; identify spatial and temporal factors influencing crossing and road mortality patterns; identify differences in crossing behavior by age-sex class and food-conditioned status; and assess the spatial relationship between highway crossing, mortality, and planned locations of wildlife passages.

STUDY AREA

I analyzed black bear movement on and adjacent to the Flathead Indian Reservation, Montana, home to the Confederated Salish and Kootenai Tribes (CSKT). U. S. Highway 93 runs north-south through the Flathead Indian Reservation, and consists of four lanes up to the southern boundary of the Reservation at the town of Evaro, where it becomes a two-lane highway. This highway has recently incurred a dramatic increase in traffic volumes and development. High traffic volumes on this highway are approximately 8030 vehicles/day in the Evaro area and 6800 vehicles/day in the Ravalli area (Montana Department of Transportation et al. 2000). The Montana Department of Transportation (MDOT) is widening most of Highway 93 between Evaro Hill and Polson to four lanes. This improvement will include placement of 42 wildlife crossing structures capable of providing passage across the highway to a variety of species and fencing to direct animals to these structures (Montana Department of Transportation et al. 2000).

The study area is on the southwestern edge of the Northern Continental Divide Ecosystem (USFWS 1993), and encompasses Highway 93 from Evaro Hill to St. Ignatius, as well as a short segment of State Route 200 west of Ravalli junction (Figure 1.1, Chapter I). This area will contain 26 of the 42 planned wildlife passages. The study area contains primary wildlife linkage habitat necessary to maintain connectivity between the Northern Continental Divide Ecosystem to the northeast and the Salmon-Selway Ecosystem to the southwest (Metz 1994, Servheen et al. 2001). The southern study area is characterized by almost continuous forest cover (77%) with few agricultural fields in the valley lands, while the northern part is characterized by patchy forest cover (25%) intermixed with wide expanses of Palouse Prairie and agricultural fields. The study area is largely within the boundaries of the Flathead Reservation, but is characterized by a mixture of private, tribal, federal, and state lands. Forest cover is predominantly coniferous, but deciduous types are found along streams, irrigation ditches, and ponds, especially in the valley bottomlands. Bear foods include berries and non-native fruit trees, which are abundant near developed areas concentrated along the highway (Servheen 1983).

METHODS

Trapping, Collaring, Monitoring, and Identification of Food-conditioned Bears

I trapped bears using Aldrich foot snares and culvert traps using standard techniques (Jonkel 1993) and outfitted them with Telonics Model 3500 GPS collars (Telonics Incorporated, Mesa, AZ, U.S.A.) programmed to collect hourly locations 24 hours a day. I conducted trapping activities within 3.2 km of the highway between 1 August and 15 August in 2002 and between 15 May and 1 July 2003. I programmed collars to disengage from bears by 1 November in 2002 and 15 October in 2003. I placed greater emphasis on collaring adult bears, but collared any bear over 34 kilos (minimum weight such that the collar would be <2.5% of the bear body mass) after a specified cut-off date to assure all collars would be deployed. I monitored VHF beacons on the GPS collars daily for mortality signals, and retrieved collars from the field when mortality signals were detected.

Starting in 2003, I used a combination of several methods to identify food-conditioned bears. I defined food-conditioned bears as those that consistently sought and received human-related foods (such as garbage or dog food) at human development sites along the highway. Bears that showed signs of previous capture were identified as potential food-conditioned bears. When I located bears near human developments, I interviewed landowners to determine if they had experienced nuisance bear activity or had seen collared bears. I collaborated with tribal wardens to identify research bears involved in nuisance activity, and compared tribal nuisance bear trap sites to bear GPS data locations. I analyzed whether movement paths of bears tended to intersect or skirt developed areas. I used cluster analysis and classification trees to identify groups of bears based on the percentage of GPS locations within 10 m, 25 m, 50 m, 100 m, and 200 m of development structures.

Identification of Road Mortalities

I identified historical bear mortality locations using records from Montana Fish Wildlife and Parks (FWP) and MDOT that were referenced to mile post markers and accurate to approximately 1/10th of a mile (~ 0.0161 km). Historical mortality locations were digitized with the program ArcView (ESRI, Redlands, CA, USA) by using highway and milepost marker layers that had been collected by MDOT using a high-grade GPS unit. During 2002 and 2003, I documented bear road mortalities in collaboration with tribal wardens, FWP, and MDOT maintenance crews. Mortality locations were recorded with a handheld GPS either by finding the carcass on the road or by navigating to the mortality location based on verbal descriptions of the location. When possible, I identified the exact impact site by searching for collision evidence remaining on the road. When carcasses were available, I documented sex, retrieved a tooth for aging, and pulled a hair sample for genotyping.

Traffic Volume

Traffic volumes were recorded in collaboration with Western Transportation Institute (WTI) and MDOT. In 2002 and 2003, I recorded hourly traffic volumes on road segments in the southern (Evaro) and northern (Ravalli) portions of the study area with traffic counters (Jamar Technologies, Willow Grove, PA) provided by WTI. In 2003, I also recorded traffic volumes on Highway 200 to more accurately estimate traffic volumes associated with crossings on Highway 200 as well as Highway 93 north of Ravalli Junction. To fill in information gaps when traffic counters failed, I also obtained hourly traffic count data for both years from a permanent counter near Ravalli maintained by MDOT.

Spatial Data Collection and Geographic Information Systems

I collected GIS spatial layers from a variety of sources. Streams, secondary roads, development points, landownership, a 10-m digital elevation model, and 1-m resolution aerial photographs of the highway corridor were obtained from CSKT. Topographic maps and digital ortho-quads (DOQQs) were obtained from the Montana Natural Resource Information System (NRIS) website (http://nris.state.mt.us/gis). I obtained digital layers of Highway 93, Highway 200, and mile post markers from MDOT. I obtained locations of wildlife passages and fencing from one of the contractors for the highway improvement project (Skillings and Connolly, Missoula, MT, USA). I created a cover layer by digitizing tree cover adjacent to the highway from aerial photographs of the highway corridor (1998), DOQQs, and field-checking. Slope and elevation data were derived from the digital elevation model. The development point layer was updated by analyzing aerial photographs and DOQQs and digitizing missing structures.

Identification of Highway Crossings

I downloaded GPS collars and used correction files from Missoula and Kalispell base stations to differentially correct the data. I used Animal Movement Extension (Hooge and Eichenlaub 2000) in ArcView to create a movement path for each animal by connecting sequential GPS locations. I defined a highway crossing location as the point at which a bear movement path intersected the highway. I identified the time between the pre- and post-crossing locations to determine the relative precision of the location. I recognized that increased time between pre- and post-crossing locations, GPS error, and tortuosity of the highway could all impact accuracy of estimated crossing locations. If a bear were standing on the side of the highway, GPS error could easily put the location on the wrong side of the highway, which would result in substantial bias because this would place 2 crossings in a location where the bear was deterred from crossing.

To assure accuracy and precision in the dataset, I developed stringent criteria to define crossings, including: crossings be 1 hour apart; pre- and post-crossing locations be on opposite sides of the highway; and post-crossing locations be a minimum distance across the highway to assure a crossing actually took place. Graves (2002) tested Telonics GPS collars and found that 2-dimensional (2D) differentially corrected positions had a circular error probability of 67 meters and 3-dimensional (3D) differentially corrected positions had a circular error probability of 22 meters. Therefore, I required that all 2D and 3D differentially corrected post-crossing positions be a minimum of 67 and 22 meters from the highway, respectively. However, not all positions were differentially corrected. Because differential correction can improve location error up to a maximum of 25 meters (Graves and Waller 2005), I required that 2D and 3D post-crossing positions that were not differentially corrected be at least 92 and 47 meters across the highway, respectively.

Analysis of Highway Permeability

To gauge highway permeability, I determined how many research bears had crossed a highway at least once. I calculated the number of male, female, and subadult bears that crossed the highway at least once as well as the sex-age classes of bears killed on the highway. Finally, I used Mann-Whitney U tests to evaluate differences in crossing frequency between different classes of bears.

To determine whether crossing bears crossed the highway more, less, or as frequently as expected, I compared the percent rank of the actual frequency that a given bear crossed the highway to a distribution of randomly generated highway crossing frequencies. I created a Monte Carlo probability distribution by determining the crossing frequency for each of 100 correlated random walks that were simulated within the 100% minimum convex polygon home range (Figure 2.1, Table 2.1) of each bear (Burt 1943), such that each walk utilized the distribution of distances and turning angles from the original bear movement path. Correlated random walk simulations were created using a script (T. Graves, unpublished script, University of Montana, Missoula, MT, USA) adapted from the Trajectory Analyst extension (Miller Mountain consulting, Durango, CO) in ArcGIS 8.2 (ESRI, Redlands, CA, USA). If a real bear's crossing frequency had a percent rank of < 0.05, this would demonstrate that it crossed the highway significantly less than expected given the location of the bear's home range; if the percent rank was > 0.95, this would demonstrate that it crossed significantly more than expected. A rank between these values would indicate the bear crossed as expected.

Analysis of Temporal Characteristics of Crossings and Roadkills

I assessed whether bears were more likely to cross the highway during hours of the day or weeks when they are most active or when traffic volume was lowest. I tested the significance of any linear relationships using a Pearson product-moment correlation coefficient. I used a Mann-Whitney U test to determine if the mean speed of movement during crossing times was different than during non-crossing times. I assessed whether any trends existed between the number of roadkills and the number of crossings by month for either all data combined or for 2003, for which I had more representative data for monthly comparisons.

I obtained sunrise and sunset tables for Missoula, Montana from the U.S. Naval Observatory Astronomical Applications Department (http://aa.usno.navy.mil). From these tables, I calculated whether or not it was dark for the specific hour and day during which bears crossed the highway. Darkness was defined as the time between civilian sunset and sunrise.

Analysis of Spatial Distribution of Crossing Locations and Roadkills

To determine at what scale crossings and roadkills are spatially clustered along the highway, I conducted a cluster analysis using a linear version of Ripley's K-statistic (Ripley 1981) adapted from Clevenger et al. (2003) and O'Driscoll (1998). For highway crossings, I included crossings on both Highway 93 and Highway 200. Because I only had one roadkill record along Highway 200, I excluded it and used the remaining points (n = 36) to assess the level of spatial clustering of roadkills on Highway 93 only. I used Random Point Generator extension for ArcView 3.x (Jennes 2001) to create 100 sets of random locations on highways for both roadkills and crossings. Because all roadkill locations are independent, I created random roadkill locations, in an amount equal to the number of roadkills, along the entire stretch of Highway 93. I created random crossing locations along the stretch of highway within each bear's minimum convex polygon home range in an amount equal to the number of crossings associated with the respective bear. I calculated the linear distance along the highway between all points within each subset (Graves, unpublished scripts, University of Montana, Missoula, MT, USA). I generated K-statistics for real and random locations, and tested the null hypothesis that the real locations were randomly distributed by comparing the actual mean to the mean of the 100 simulations. I determined the scale of spatial clustering or dispersion by graphing the difference between the actual mean and the average of the simulated means in comparison to the 95th percentile of the distribution.

To assess the potential effectiveness of planned wildlife passages, I used a Mann-Whitney Rank Sum test to analyze whether crossings and mortalities occurred closer than random to planned locations for large mammal crossing structures (n = 20). Because roadkills may coincide with crossings but all crossings may not necessarily coincide with roadkills (McGown and Eason 2001), I assessed both relationships. I used Mann-Whitney tests to assess if the relationship of distance from roadkill to crossing locations and from crossing to roadkill locations were different than distances to respective distributions of random points. I created random locations in the same manner as above, but used only one distribution of random points for comparison. I then graphically mapped the locations to better understand the spatial relationship of these variables to one another.

Analysis of Temporal and Micro-site Characteristics of Crossings and Roadkills

Crossings

I employed logistic regression and maximum likelihood techniques to estimate the probability of bears crossing the road given the occurrence of specific factors that may influence bear crossing activity. I used a dichotomous response variable where used (real) crossings locations were contrasted with available (random) crossing locations (Manly et al. 1993). Random crossings were created on sections of highway within each bears home range and in equal proportion to the number of real crossings by each bear (Jennes 2001). I then used two methods of model selection, to analyze what factors influence bear crossing activity. The first method I used was an information theoretic approach using Akaike's Information Criterion (AIC) following methods outlined in Burnham and Anderson (1998). The second method was an ad-hoc analysis using backwards stepwise selection and logistic regression methods outlined in Hosmer and Lemeshow (2000). My goal for doing this second, ad-hoc analysis was to obtain a parsimonious model that did not contain insignificant terms, after considering all reasonable combinations of factors. I present both analyses for comparative purposes.

I developed a list of 15 candidate variables and 5 interaction terms based on a literature review and expert-based opinion. These factors included: darkness, traffic volume, distance to cover, the percent cover within a 200 m buffer, distance to stream, distance to a stream crossing of the highway, length of stream (i.e. riparian habitat) within a 200 m buffer, mean slope within a 200 m buffer, standard deviation of elevation within a 200 m buffer, distance to development, number of developments within a 200 m buffer, distance to guardrail, distance to guardrail endpoint, density of roads within a 200 m buffer, and open (Ravalli) vs. continuously forested (Evaro) landscape. The 200 m buffer around the crossings was chosen because 75% of pre-crossing locations were within 200 m of the highway. I also calculated 4 interaction terms I believed could influence crossing activity: distance to cover x open habitat, percent cover x open habitat, distance to cover x darkness, and distance to development x darkness. Measurements for all variables were calculated using extensions in ArcView 3.x and ArcGIS 8.x (Jennes 2002, Raimondo 2003, Beyer 2004) except darkness and traffic volume (see temporal data collection). To assure that correlated variables would not be included in the same model, I screened all variables for multicollinearity using a Pearson correlation coefficient, and defined variables with coefficients higher than 0.50 to be correlated.

I constructed 16 models *a priori,* including a null model with only a constant term and global model with all non-correlated variables. I used SPSS software to conduct logistic regressions to obtain the -2 log-likelihood for the AIC selection process and to analyze the goodness of fit of the models using the Hosmer and Lemeshow test statistic. I used AIC and selection ratios to identify a "best AIC model".

After completing the AIC process, I conducted a second logistic regression process using stepwise selection to obtain a "best stepwise model." I began by testing all main-effect variables for significance using univariate logistic regression (for continuous variables) and contingency tables (for categorical variables). I then explored the importance of interaction terms by testing only these terms with their associated main-effect variables. Insignificant interaction terms and main-effect variables were excluded from further consideration. I constructed a set of 17 initial "full models" that included all possible combinations of uncorrelated main-effect variables that had displayed univariate significance. I conducted backwards stepwise selection by using X^2 tests of Wald stastistics to iteratively remove non-significant terms and obtain the most parsimonious "reduced models." The "best stepwise model" was the one with the lowest -2 log-likelihood (-2LL) value that passed the Hosmer and Lemeshow goodness of fit test ($p > 0.05$).

I conducted a K-fold cross validation process adapted from Boyce et al. (2002) on both final models to 1) see whether models had good predictive capabilities and 2) to see whether one model performed better than the other. I performed a 3-fold cross-validation because of limitations in sample size. This process involved constructing three mutually exclusive "test sets" by randomly selecting 1/3 of the data 3 times, without replacement. I then ran the logistic regression of the best models again, using only the data not included in a given test set, to determine independent coefficients that could be used in calculating a resource selection function for that test-set. I estimated the resource selection probability function on each test set (equation 8.7 from Manly et al. 1993), which takes the log-linear form:

$$w(x) = \exp(B_1x_1 + B_2x_2 + \ldots. + B_px_p).$$

I divided both the used and available RSF scores into bins such that each bin had at least one available point and that no more than one bin had <1 used points. I calculated an average subset by averaging the number of used and available points in each bin across all subsets. To adjust for availability on the landscape, I calculated an adjusted crossing frequency by dividing the number of real crossings by the number of available points in the same bin. I consecutively numbered each bin so that the bin with the lowest range of RSF scores was lowest and that with the highest range RSF score was highest. I then ranked each bin based on the adjusted crossing frequency, and conducted a Spearman Rank Correlation test to determine the predictive capabilities of the model. Because a model with good predictive capabilities would be putting more real crossings in the higher RSF score bins, a strong correlation coefficient and linear trend in the data would indicate a good model (Boyce et al. 2002).

I conducted several analyses to try to assess whether the models might be influenced by food-conditioning or behavior of individual bears. I used a different method for each model selection process. For the AIC model selection process, I first separated the data of bear crossings into two sets: food-conditioned bears and non food-conditioned bears. I then ran all 16 of the models with only food-conditioned bears and verified whether I came up with the same best model. I could not run all the models with only non food-conditioned bears because of small sample size (n = 19). To evaluate if an individual bear might be influencing the data set more than the others, I then ran all 16 models 10 more times, each time leaving out a different bear, and checked whether the best model remained consistent across data sets.

I could not use the same methods for the stepwise model selection procedure, because through the stepwise regression process I would not come up with a consistent set of comparable models. Instead, I separated out food-conditioned bears, and cross-validated the model using coefficients from the "best stepwise model" to evaluate whether the model adequately reflected the food-conditioned bears by themselves. I could not do this for non food-conditioned bears because small sample size precluded subset creation.

Roadkills

I tested whether the variables used in the crossing location analyses might also be associated with road kill locations. I compared roadkill locations to random points created along the entire stretch of highway within the study area. Random points were created in direct proportion to the number of roadkill locations. I did not have exact times of death for roadkills, and so did not include traffic volume or darkness in this analysis. Due to low sample sizes, I used only univariate logistic regression analyses on the remaining variables.

RESULTS

Trapping, Collaring, Monitoring, and Identification of Food-conditioned Bears

I collared 8 bears in 2002 and 11 bears in 2003, with one recapture in 2003. Of the 18 collared bears, there were 8 adult males, 6 adult females, and 4 subadult males. I classified 5 of these bears as food-conditioned: three bears were trapped by Tribal wardens at nuisance activity sites, 2 were documented in nuisance behavior through tracking and landowner interviews, and one that was consistently located near developments had patterns of movement similar to the other food-conditioned bears (see Chapter III). Number of times individual bears were located via

GPS technology (Figure 2.2) varied (mean = 1774, range = 308 - 3898) because: the 2002 field season began later; some bears were captured earlier in the season than others; some bears died or shed their collars before programmed release dates; and due to differential GPS fix success rates (mean = 70%, range = 19% - 90%). A total of 31,780 locations were available for analyses from the 18 collared bears combined. All but 3 bears had GPS fix success rates over 65% (Table 2.2).

Identification of Road Mortalities

I documented 37 black bear road mortalities for the period between 1995 and 2004, 36 of which were on Highway 93 and 1 of which was on Highway 200 (Table 2.3). This did not represent all mortalities in the area, as historical records were incomplete. The 2002 and 2003 mortality rates that I recorded are likely a more accurate reflection than historical records of the high number of yearly bear mortalities that occur in this area. Of the 37 mortalities, 21 occurred during the study period: 10 in 2002 and 11 in 2003. Although my research may be more accurate, this should be considered a minimum count for these years, as bears are often quickly taken from the road side for their claws, skulls, and hides. Several carcasses were missing one or more of these body parts. In addition, road kill counts usually underestimate road mortalities because fatally injured animals often die after moving away from the roadside, where they cannot be counted (Wooding and Maddrey 1994). I ascertained the age-sex class of 19 of the 37 road mortalities recorded between 2001 and 2004: 2 adult females (11%), 4 adult males (21%), 5 subadult females (26%), and 8 subadult males (42%). Subadults comprised 68 % of road mortalities for which sex was known.

Traffic Volume

Using data recorded in the field and obtained from MDOT, I estimated hourly traffic volumes for 4 different road segments in the study area from 1 August 2002 to 1 November 2002 and from 21 May 2003 to 27 October 2003. Mean daily traffic volumes varied among segments:

Evaro (mean = 9008, range = 4610-13,154), Ravalli south of Ravalli junction (mean = 8062, range = 5231-11,534), Ravalli north of Ravalli junction (mean = 5473, range = 3661-8121), and Highway 200 (mean = 2677, range = 1751-7692). Mean hourly traffic volumes also varied between segments: Evaro (mean = 375, range = 29-703), Ravalli south of Ravalli junction (mean = 336, range = 27-620), Ravalli north of Ravalli junction (mean = 228, range = 18-421), and Highway 200 (mean = 111, range = 9-206).

Identification of Highway Crossings

I initially identified 356 crossings by 11 bears when I simply intersected bear movement paths with the highway. I then eliminated 79 crossing that were greater than one hour apart, 37 crossings because locations were on the same side of the highway (where the movement path intersected a curve in the highway), and 28 crossings that did not meet the minimum distance criteria. After removing these crossings, I was left with 212 crossings of Highway 93 or State Route 200 by 10 bears to use for analyses (Figures 2.3, 2.4, 2.5). While the time restraints and minimum distance criteria may have eliminated some crossings that actually occurred, the increased accuracy and precision of crossing locations ultimately assured spatial analyses were more robust. Only 12 of the eliminated crossings were by non food-conditioned bears. Most crossings occurred on Highway 93 (187 of 212, 88%), but Highway 200 was only within the home range of three bears.

Analysis of Highway Permeability

While sample sizes for age-sex classes are small, adult males in this study area crossed the highway less than adult females and subadult males. Of the 18 bears collared in the study area, 3 of 8 males crossed highways, 4 of 6 females crossed highways, and 3 of 4 subadult males crossed highways. Of the 10 bears that crossed highways at least once, adult males crossed less frequently (n = 17) than females (n =126) or subadults males (n = 69). These results were not analyzed statistically due to the confounding effects of food-conditioning.

Of the 10 bears that crossed highways, 5 were food-conditioned. Age-sex ratios of food-conditioned (2 females, 2 subadult males, 1 adult male) and non food-conditioned (2 females, 1 subadult male, 2 adult males) crossing bears were similar. The food-conditioned bears, however, crossed highways significantly (z = -2.62, p = 0.009) more frequently (n = 193, 91%) than non food-conditioned bears (n = 19, 9%). This relationship would be stronger if only considering Highway 93. Most crossings by non food-conditioned bears, by a small margin, were on Highway 93 (11 of 19). However, non food-conditioned crossings on SR 200 (n = 8) were all by bear 518, who also crossed Highway 93 (n = 1). Therefore, the number of crossings per non food-conditioned bear was much higher on low-traffic volume Highway 200 than Highway 93.

Correlated random walk (CRW) analyses initially indicated that 4 non food-conditioned bears crossed the highway less frequently than expected and one crossed as expected, while 4 of 5 food-conditioned bears crossed the highway as expected. One food-conditioned bear crossed the highway less than expected; however, it had low fix success (23%). I suspected that the stringency with which I selected final crossings for analyses may have influenced the outcome of this analysis. Of the 79 crossing locations removed due to time constraints, 37 locations were from this bear. Because location precision is not important for this particular analysis, I included these crossings back into the analysis. Revised results of CRW analyses (Table 2.4) were the same for all bears except this bear, which crossed the highway more frequently than expected. However, bear 525, a food-conditioned bear, also crossed more than expected at the p = 0.10 level. Because I had captured bear 517 for two seasons, I checked to see if there was any difference in crossing frequency between the 2 years. This bear, which was a food-conditioned bear, crossed as expected both years.

Analysis of Temporal Characteristics of Crossings and Roadkills

Bears crossed the highway most in the early morning hours when mean movement rates and traffic volumes were lowest, but also crossed during evening hours when their mean movement rates were highest (Figure 2.6). There was a strong, negative linear relationship between the number of highway crossings and hourly traffic volume ($r = -0.835, p < 0.001$). Spring through early summer, bears crossed the highway relatively little despite high movement rates, and crossed during relatively high traffic volumes as compared to traffic during crossings later in the year (Figure 2.7). Beyond an asymptote at approximately Julian week 33 (mid-August), bear crossing activity patterns seem to follow mean movement patterns. Mean speed of movement during hours bears crossed the highway was significantly higher ($Z = -15.919, p < .001$) than mean non-crossing speeds for those same hours, and crossing speeds were highly variable during daylight hours when traffic volumes were highest (Figure 2.8). I found no trends between the number of crossings and number of roadkills by month for either 2003 or all data combined.

Temporal patterns of crossings depended on age-sex class and food-conditioned status (Table 2.5). Of the 212 bear crossings, 73% ($n = 154$) occurred when it was dark and traffic volumes were relatively low. Of the 10 bears that crossed the highway, 9 crossed during the day at least once: 4 females (2 food-conditioned), 3 adult males (1 food-conditioned), and 2 subadult males (1 food-conditioned). Daytime crossings ($n = 58$) were 35% ($n = 20$) adult female, 5% ($n = 3$) adult male, and 60% ($n = 35$) subadult male. The relative percentage of daytime crossings (# daytime crossings for a given class/total number crossings for the same class) for each age-sex class was 16% for females, 18% for adult males, and 51% for subadult males. Food-conditioned bears were responsible for 90% (52 of 58) of daytime crossings and 92% (141 of 154) nighttime crossings. The 2 non food-conditioned females crossed the highway only once during the day, but crossed during late hours of the day. In addition, daytime crossings of non food-conditioned females occurred either on Highway 200, which had much lower traffic volumes, or Sunday, which was the lowest traffic day of the week.

Field season length was different in 2002 than 2003, so I also identified the number of day and night crossings for bears by year, age-sex class, and food-conditioned status (Figure 2.9). Extremely small sample sizes and data inequalities between years preclude any substantive evaluations. However, the data indicates that: non food-conditioned subadult and adult males crossed very little but crossed as much during the day as at night; non food-conditioned adult females crossed more at night than during the day; 1 food-conditioned subadult male was responsible for most daytime crossings; and relatively few daytime crossings occurred in the Fall regardless of food-conditioned status.

Analysis of Spatial Distribution of Crossing Locations and Roadkills

Crossing and roadkill locations were not randomly distributed along the highway. Crossings were clustered at all spatial scales below 17 km (1-17 km), with the highest intensity of clustering between 3 and 6 km (Figure 2.10). Crossings were randomly distributed at 18 km and dispersed thereafter. Roadkill locations were clustered between 0.20 km and 15 km, with the highest intensity of clustering between 9 and 13 km (Figure 2.11). I found no dispersion of roadkill locations.

Roadkill locations were significantly closer to crossing locations ($Z = -2.545$, $p = 0.011$) and wildlife passage locations ($Z = -1.887$, $p = 0.059$) than a distribution of locations placed randomly along the highway. Crossing locations were closer to wildlife passage locations ($Z = -4.008$, $p = <0.001$) and roadkill locations ($Z = -8.086$, $p < 0.001$) than a distribution of random locations placed on highway segments within each bear's 100% MCP home range. A graphical representation of the highway corridor supported that crossing, roadkill, and planned locations of wildlife passage have similar spatial distributions (Figure 2.12). However, certain areas exist with high levels of crossings and/or roadkills where no planned locations of passages are nearby and where no fencing is planned to direct wildlife to passages. In addition, the distribution of development along the highway may reduce accessibility of certain passages (Figure 2.13). I found that only 18% of non food-conditioned crossings, 40% of food-conditioned crossings, and 46% of roadkills were within 200 m of wildlife passages, and crossings occurred infrequently near passages with high amounts of development within 200 m (Figure 2.14).

Spatial and Temporal Characteristics of Crossings and Roadkills

Crossings

- AIC Regression: The AIC model selection process resulted in 2 top models within 2 ΔAIC of each other, which differed by only 1 variable. Although the top model (k = 8, *wi* = 0.663, evidence ratio = 1) had fewer variables, it failed the Hosmer and Lemeshow goodness of fit test ($p = 0.046$), so I chose the better-fitting ($p = 0.508$) model (k = 9, *wi* = .276, evidence ratio = 2.399) as the final AIC model. The final AIC model (Table 2.6) included 5 main effects (darkness, distance to development, stream length (m) within 200 meters, distance to cover, open habitat) and 2 interaction terms (distance to cover x open habitat and distance to cover x darkness). However, because estimates for 2 variables (distance to development and the interaction of distance to cover with darkness) were not statistically significant, odds ratios cannot be interpreted with confidence. Because there is an interaction between open habitat and distance to cover, I only interpret the exact measure of the effect of distance to cover with respect to habitat. Bears were: 6 times more likely to cross at night (95% C.I. 2.35-15.43); 1.001 (95% C.I. 1.001-1.002) times more likely to cross for every 1-m increase in stream length; and less likely to cross with every 1-m increase in the distance to cover when in open habitat areas, where there is little cover.

- Stepwise Regression: Only 2 variables were not significant in univariate analyses of crossing locations (Table 2.7): the road density and number of developments within 200m. The only significant interaction terms were distance to cover x open habitat and percent cover x open habitat. The final model (Table 2.8) using stepwise selection consisted of 5 main effects (darkness, distance to development, distance to stream crossing, percent cover within 200m, and open habitat) and 1 interaction term (percent cover within 200m x open habitat). The negative 2 log-likelihood (-2LL) was 20 points lower than any of the other competing models, and it passed the Hosmer and Lemeshow goodness of fit test (-2LL = 455.687, H-L X^2 = 13.188, H-L $p = 0.106$, Nangelkerke $R^2 = 0.357$). These results indicate that the odds of a bear crossing are: 5 times more likely to happen at night (95% C.I. 3.15-8.17); 1% less likely to happen with 1-m increase in distance to development (95% C.I. 0.996-0.999); 1% less likely with each 1-m increase in the distance to a stream crossing; and more likely to happen with each percent increase in square meters of cover in open habitats.

- Cross-Validation: Cross-validation demonstrated that both the AIC-selected model and the Stepwise-selected model performed well (average model: $r > 0.964$, $p < 0.001$). The correlation coefficients are strong for both models (Table 2.9), but the linear correlation in the stepwise model was stronger for all subsets.

- Influence of food-conditioning and individual bear on model selection: I tested whether the same best model would be chosen using AIC if either a jackknifing procedure was employed to iteratively leave each bear out of each model or if the model was based on crossing locations of only food-conditioned bears. The best AIC model (model 15) came out in the top 3 candidate models every time, and was usually within 2 ΔAIC of the best model. Model 14 was better (ΔAIC >2) for models without bear 511, without bear 513, and for the model with only food-conditioned bears. This indicates that there is a weak effect of individual bear and food-conditioning on the selection of the best model. Significant terms in Model 14 that differ from those used in Model 13 or 15 include 1) percent cover within 200 m instead of distance to cover (Wald 6.083, $p = 0.014$), 2) distance to stream instead of stream length (Wald 7.432, $p = 0.006$), and 3) the interaction between number of developments and darkness (Wald 5.572, $p = 0.018$). Model 14 also contained a number of insignificant terms. To test the robustness of the best stepwise model, I ran the cross-validation procedure on the final best model using only the food-conditioned bears. The strong linear correlation (average model: $r = 0.952, p < 0.001$) in the data demonstrate that the stepwise model did a good job of predicting crossings by food-conditioned bears (Table 2.9).

Roadkills

The following main effects and interactions terms were insignificant in univariate tests: distance to development, number of developments within 200 m, distance to guardrail, distance to guardrail endpoint, distance to stream, road length within 200 m, mean slope within 200 m, standard deviation of elevation within 200 m (Table 2.10). Five univariate models were significant ($p < 0.05$). Odds ratios indicated that roadkills were: 8% less likely to occur (95% C.I. 3% to 13%) with each 100-m increase in distance from a stream crossing; 1.26 (95% C.I. 1.05- 1.51) times more likely to occur with each 100-m increase in stream length/riparian area within 200 m; 69% less likely to occur (95% C.I. between 17% and 89%) with each 100-m increase in distance from cover; 1.00003 more likely with each 1-m^2 increase in cover (95% C.I. 1.000006 to 1.00005); and 65% less likely to occur (95% C.I. 1% - 98%) in open habitat areas. Multivariate analyses were not possible given sample size.

DISCUSSION

Highway Permeability and Temporal Patterns Crossings and Roadkills

Permeability of highways, defined by a bear's ability to cross and frequency of crossing, depended primarily on the food-conditioned status of the bear. Despite high traffic volumes, Highway 93 was fully permeable to food-conditioned bears ($n = 5$), which were responsible for most crossings (91%). However, Highway 93 was, at the very least, a partial barrier to non food-conditioned bears, which crossed seldom ($n = 5$) or not at all ($n = 8$). A significant difference in crossing frequencies between food-conditioned and non food-conditioned bears is strong evidence that food-conditioning is related to crossing behavior. Therefore, I was not surprised when CRW analyses indicated that non food-conditioned bears crossed highways less frequently than expected. This trend has also been found for grizzly bears using similar analysis techniques (Waller and Servheen 2005, T. Graves, unpublished data, University of Montana, Missoula, MT, USA). However, given the high frequency of crossings by food-conditioned bears, I was surprised to find that most crossed highways as expected. On further reflection, I realized this pattern may be an artifact of my analysis technique: the correlated random walk analysis limited movement paths to the extent of each individual bear's home range. Home ranges of food-conditioned bears were more centered on the highway than home ranges of non food-conditioned bears, making the probability that a random movement path would intersect the highway higher. Therefore, my inability to demonstrate that food-conditioned bears crossed more than expected may not be a true reflection of their behavior, especially given the extremely high number of crossings by these bears. In contrast, non food-conditioned bear home ranges were more peripheral to the highway, so a random movement path would be less likely to intersect the highway. Therefore, my finding that non food-conditioned bears crossed less than expected provides even stronger evidence of avoidance. The idea that non food-conditioned bears may live close to highways but avoid crossing is supported elsewhere in the literature. Beringer et al.

(1990) found that highway crossing avoidance by black bear increased linearly with longer segments of a highway in the bear's home range, and Kaczensky et al. (2003) found no avoidance by grizzly bears of habitats adjacent to highways despite very low frequency of highway crossings.

My results indicate that the highway is least permeable to adult males, primarily due to avoidance behavior. The majority (63%) of adult males did not cross the highway, while those that crossed did so very little (n = 17) in comparison to other age-sex classes. Despite infrequency of crossing activity, adult male mortality was somewhat higher than that of adult females, which suggests that they may not be as familiar with optimal crossing times or locations. While my sample size for each age-sex class was small, non food-conditioned males crossed as much during the day as they did at night, which supports the idea that they may not be as familiar with traffic patterns. The adult food-conditioned male in my study crossed more often than other males, but did not cross during the day, possibly because of a greater familiarity with the highway corridor and human activity patterns. My results contrast with those of McGown and Eason (2001), who found that adult males cross highways at similar rates to adult females, but this may be partially due to differences in acquisition protocols and sample size of location data.

My results also indicate that highway permeability is compromised for young and inexperienced bears, primarily due to mortality associated with crossing behavior. The subadult bears in our study were less discerning than adult about when or if they cross highways. Of the 19 mortalities for which age-sex data was available, 68% (n = 13) were subadults. This higher mortality is likely the result of crossing highways often and crossing during daytime hours when traffic volumes are high. The majority of subadult males crossed the highway, they were responsible for 63% of daytime crossings, and they crossed highways during the day 50% of the time. Food-conditioned subadults are at highest risk of mortality because they cross frequently during hours with high traffic volumes.

Learning behavior may lessen barrier effects associated with highways for adult females living within the highway corridor. The majority of adult females crossed the highway, and they crossed more often than other age-sex classes. However, adult females crossed during daytime hours only 16% of the time, and constituted only 11% of documented road mortalities. These results suggest the demographic effects associated with crossing may not be equal for all age-sex classes. I expected highways to have a larger demographic effect on age-sex classes that cross highways more frequently, because they would have a higher probability of being killed due to vehicle collisions. This was true for subadult males, but did not hold for adult females. This difference is due to the fact that adult females, regardless of food-conditioning, usually choose to cross highways when traffic volumes are low. Previous research has indicated that there may be some level of learning behavior involved in highway crossing activity (Beringer et al. 1990, Gibeau 2001). My results suggest this learning behavior may be enhanced only for adult females. This is likely due to intraspecific competition. Dominant adult males often restrict females to marginal habitat areas near highways (Mattson 1990), which may give females that survive to adulthood more opportunity to learn when and where it is safest to cross. This possibility is supported by the pattern I found that crossing activity was highest in the early hours of the morning when bears were least active. Adult females seemed to make a point of crossing when it is safest to do so, even though they are not normally as active at these times. Indeed, the majority of adult female crossings (84%) occurred at night when traffic volumes were low.

While bears crossed highways often, they still exemplified disturbance behavior while doing so. I found that adult females avoided highway crossing during high traffic times in general, and other age-sex classes avoided crossing during high traffic times late in the season. These results are consistent with previous black bear studies that found high traffic volumes associated with low levels of bear crossing activity when comparing high and low volume highways (Brody and Pelton 1989, Beringer et al. 1990, Brandenburg 1996). Results are also similar to those for grizzly bear studies that analyzed specific crossing times, which were based on locations collected at 1-hour (Waller and Servheen 2005), 6-hour (T. Graves, unpublished data, University of Montana, Missoula, MT, USA) or 24-hour intervals (Gibeau et al. 2001). Furthermore, I found that bears moved more quickly when crossing highways than they normally moved during those same hours of day when not crossing highways. Standard errors of crossing speed estimates were small, except during daylight hours, when traffic volumes are highest. Because speed is both a function of time and distance, the high variability in crossing speeds during daylight hours may be explained by either factor. Individual bears likely respond differently to high traffic volumes. For example, some bears may wait next to the highway for extended times before finding the opportunity to cross, resulting in a lower speed. In contrast, other bears may simply dash across and away from highways quickly, resulting in a higher speed.

Frequency of highway crossings did not appear to be simply a result of lower or higher movement rates. While bears did cross highways in evening hours when their activity was highest, they crossed most often in the early morning hours when their movement activity was normally lowest. These results strongly resemble crossing activity patterns of grizzly bears reported by Waller and Servheen (2005). Seasonal crossing patterns were also not correlated with movement rates. Early in the season before berries are ripe, bear activity levels are typically higher due to the need to search for scarce food resources. While I did find that average movement rates of black bears were highest late spring and early summer, this is when bears crossed highways the least. Further inspection revealed that one subadult male crossed highways relatively often during this time, but adult females did not. Females crossed the highway the most in my study, but did so later in the year. Because 3 of 4 of adult females had cubs at the time of capture, lack of crossing activity early in the year may indicate that even food-conditioned females with cubs are hesitant to cross highways or approach developed areas until cubs are older. Alternatively, adult females may not cross simply because resources along highways are not yet available (Carr and Pelton 1984). The early-season, high-traffic crossings made by subadult males may be either the result of adult males excluding subadults from higher quality habitats farther from highways (Mattson 1990, McGown and Eason 2001), or it could be attributed to exploratory behavior by these young bears that are not as familiar with the location of available resources.

Increased crossing activity may be associated with bears accessing seasonally available resources within riparian habitat along the Jocko River and other creeks that parallel much of Highway 93. Crossing activity of black bears increased after Julian weeks 32, which coincides with the end of July and the onset of prime berry season. In addition to berries, the area adjacent to the highway contains a large number of fruit trees, most of which are within or adjacent to developed areas. The presence of this concentrated food resource along the highway corridor provides a high motivation for bears to cross the highway. Because fruit trees and natural food resources can bring bears into close association with people, bears can become habituated to humans and human development sites (Mattson 1990). In areas where unnatural attractant sources are also readily available (garbage, livestock feed, etc) bears have a higher likelihood of becoming food-conditioned. Previous research indicates that attractant sources along highways may be a leading cause of bear mortalities due to collisions (Huber et al. 1998, Gibeau and Herrero 1998). Non food-conditioned bears of all age-classes that attempt to access such resources may have a high risk of mortality due to their potential to cross highways during higher traffic. While I found that adult food-conditioned bears crossed primarily during low traffic hours of the day, these bears still have a high probability of mortality, as they are likely to be subject to management removal.

Spatial Distribution and Characteristics of Crossings, Mortalities, and Wildlife Passages

The planned locations of wildlife passages appeared to be generally appropriate, but management of lands adjacent to passages will be critical for assuring passage efficacy, and gaps between passages where crossings and/or roadkills occur frequently will need to be addressed or bear and human safety may continue to be compromised in these areas. Crossing and mortality locations were juxtaposed along the highway and clustered relatively near planned locations of wildlife passages. Fencing that directs wildlife to passages may help mitigate demographic effects where large gaps between passages occur. Since the smallest spatial scale at which mortality locations were clustered was 200 m, this length may be an effective minimum requirement for fencing when passages overlap with roadkill clusters. However, more than half of crossings and roadkills were not within 200 m of passages, suggesting that longer stretches of fencing may be necessary to direct wildlife to the planned locations of passages. Long sections of fencing are planned for portions of Highway 93, but this fencing will not cover all areas where crossings and roadkills occurred. Demographic impacts of the highway will likely continue to be high in certain areas where crossings and roadkill counts were high, but passages and fencing were not planned.

Without proper placement and management of lands adjacent to passages, fencing could also have detrimental effects on bears. If fencing forces bears to move through areas with high levels of development and anthropogenic food sources to access wildlife passages and cross highways, bears will have a higher likelihood of becoming food-conditioned. Similarly, while proximity to development may not impede the use of wildlife passages by food-conditioned bears, wary bears may not be as likely to use them if human disturbance is high (Clevenger and Waltho 2000), and mortalities of wary bears on highways may therefore increase. While I found that food-conditioned bears crossed relatively close to development some of the time, I also found that both food-conditioned and non food-conditioned bears crossed less frequently near planned locations of passages with high amounts of development within 200 m. Prevention of new development as well as removal of current development and anthropogenic food sources from areas near passages will be necessary to assure their effectiveness for providing connectivity.

Wildlife passages are also more likely to be effective if placed near stream intersections with the highway, and in areas where greater amounts of cover will allow protected access to passage locations. Crossings and roadkills were both more likely to occur closer to cover and streams, closer to locations where streams bisect the highway, and in areas where there is a higher percentage of cover or greater stream length within 200 m. These factors should be considered when planning placement of wildlife passages and when managing lands adjacent to passages.

MANAGEMENT IMPLICATIONS

My results indicate that placement of planned wildlife passages is generally appropriate, but care must still be taken to maintain access to these structures as levels of traffic and development within the highway corridor increases. Wary bears are less likely to use crossing structures if they are close to high intensity human use areas (Clevenger and Waltho 2000). Because bears readily climb over highway fencing (Clevenger et al. 2001), passage planning must emphasize providing easy access to wildlife passages both through appropriate passage placement and by management of habitats leading up to passages. While development near most planned passage locations may not be intense at the moment, highway improvement projects are usually accompanied by increases in development activity. To promote passage use, disturbance-free habitat adjacent to passages must be created, maintained, or enhanced and landscape-level connectivity to crossing locations must be protected (Servheen et al. 2001, Clevenger and Waltho 2005). Shifting certain planned passages from areas where development intensity is high and crossings or roadkills are not occurring to areas where development is lower and crossings or roadkills are occurring may also increase the utility of passages for black bears.

Control of attractant sources is vital for facilitating safe passage for bears across highway corridors because food-conditioning reduces the probability of survival for bears. While I found food-conditioned bears crossed highways often, if they and their offspring do not live to reproduce, real connectivity across these highways is not occurring. Food-conditioned bears are removed from populations because they often become aggressive towards people and destructive towards property. Hebblewhite et al. (2003) found that 82% of all black bear mortality in Banff National Park was human-caused (highway mortalities, management removals, and management translocations) and that survival was lower once bears became a management problem. Nuisance bears on the Flathead Indian Reservation are removed from conflict areas through translocation or euthanasia at rates that range from 30 to 50 bears per year. While management removal of bears is high, the number of removals is not diminishing, which suggests that more bears become food-conditioned every year, and that removal does not ultimately resolve human-bear conflicts. Beckman (2003) found that black bears may shift from wildland habitats to urban environments and increase in density in response to the availability of human food resources (Beckmann et al. 2003). Increased bear densities in human-dominated areas, especially when human foods are not secure from bears, will likely lead to steadily increasing conflicts and bear mortalities. I suggest management focused on removal of attractant sources, especially where wildlife passages are planned or high nuisance activity is occurring. A comprehensive bear management program will need to address both the impacts of the highway and the impacts of human development on the resident bear population. Maintaining healthy bear populations and connectivity across highways will require managing our own attitudes and activity patterns as much as those of the bears

TABLES

Table 2.1. 100 % Minimum convex polygon home range sizes by bear and year northwest of Missoula, MT.

Bear ID	Food-Conditioned	Habituated	Area km^2	Area mi^2
		August 2002 – October 2002		
511	Yes	Yes	37	14
512	No	Yes	46	18
513	No	No	29	11
514	No	No	31	12
515	No	No	34	13
516	No	Yes	236	91
518	No	No	32	12
		May 2003 – October 2003		
519	No	No	703	271
520	No	No	54	21
521	No	No	439	169
523	No	No	23	9
524	Yes	Yes	102	39
525	Yes	Yes	283	109
528	No	No	79	30
530	No	No	61	23
532	Yes	Yes	160	62
534	No	No	32	12
		Both 2002 and 2003 Seasons		
517	Yes	Yes	268	103

Table 2.2. GPS fix success rates, food-conditioned status, age, and number of crossings by bear.

Bear ID	Status*	Age	Age-Sex**	Time Interval:	GPS Fix Attempts	Successful GPS Fixes	GPS Fix Success	# of Crossings
511	FC	3	SAM	08/01/02-10/15/02	1802	411	23%	18
512	NFC/HAB	2	SAM	08/03/02-09/19/02	1121	866	77%	2
513	NFC	4	AF	08/03/02-10/15/02	1751	1520	87%	3
514	NFC	9	AM	08/03/02-10/15/02	1751	1422	81%	0
515	NFC	4	AM	08/04/02-09/15/02	1001	306	31%	0
516	NFC/HAB	4	AM	08/10/02-10/30/02	1947	1604	82%	3
517	FC	4	AF	08/14/02-11/01/02	1868	1677	90%	46
517	FC	5	AF	06/26/03-10/15/03	2668	2221	83%	14
518	NFC	4	AF	08/15/02-11/01/02	1640	1526	93%	9
519	NFC	13	AM	05/21/03-09/01/03	2463	1998	81%	0
520	NFC	4	AF	05/21/03-10/15/03	3525	2647	75%	0
521	NFC	14	AM	05/25/03-10/15/03	3432	649	19%	0
523	FC	15	AF	05/28/03-10/15/03	3351	2483	74%	0
524	FC	6	AM	05/30/03-10/15/03	3315	2168	65%	12
525	FC	2	SAM	06/14/03-10/15/03	2951	2118	72%	49
528	NFC	14	AM	06/14/03-10/15/03	2947	2309	78%	2
530	NFC	2	SAM	06/18-10/15/03	2853	2483	87%	0
532	FC	13	AF	06/20-10/15/03	2786	2402	86%	54
534	FC	8	AM	06/29/03-08/23/03	1314	970	74%	0
Totals					**44486**	**31780**	**71%**	**212**

*FC = food-conditioned; NFC = non food-conditioned; HAB = habituated but not food-conditioned.

**SAM = subadult male; AF = adult female; AM = adult male.

Table 2.3. Numbers of black bear roadkills and highway crossings by month within the study area northwest of Missoula, MT.

Month	Total Roadkills	Total Crossings	2003 Roadkills	2003 Crossings
1	1	NA	0	NA
3	1	NA	1	NA
4	1	NA	1	NA
5	1	NA	0	NA
6	7	6	0	6
7	5	15	2	15
8	3	63	1	51
9	6	73	2	44
10	10	55	4	15
11	2	NA	0	NA
Total	**37**	**212**	**11**	**131**

Table 2.4. Percent rank of observed vs. expected black bear crossings indicates that non food-conditioned bears cross less than expected, while food-conditioned bears cross as expected or more than expected.

Bear ID	Percent Rank	Expected (1-hr crossings)	Percent Rank	Revised Expected (+ crossings > 1 hour)
511*	0.03	<	0.99	>
512	0.03	<	0.05	<
513	0.01	<	0.02	<
516	0.27	=	0.27	=
517* (total)	0.58	=	0.62	=
517* (2002)	0.60	=	0.66	=
517* (2003)	0.75	=	0.82	=
518	0.00	<	0.01	<
524*	0.09	=	0.16	=
525*	0.67	=	0.94	=
528	0.05	<	0.05	<
532*	0.83	=	0.86	=

*** Indicates a food-conditioned bear**

Table 2.5. Summary of day and night crossings of black bears by age-sex class and food-conditioned status.

			Highway Crossings				
Status	**Class**	***N***	**# Day**	**# Night**	**Total**	**% Day**	**% Night**
Food-conditioned	Adult Female	2	18	96	114	16%	84%
	Adult Male	1	0	12	12	0%	100%
	Subadult Male	2	34	33	67	51%	49%
Total		**5**	**52**	**141**	**193**	**27%**	**73%**
Non Food-conditioned	Adult Female	2	2	10	12	17%	83%
	Adult Male	2	3	2	5	60%	40%
	Subadult Male	1	1	1	2	50%	50%
Total		**5**	**6**	**13**	**19**	**32%**	**68%**
All Bears	Adult Female	4	20	106	126	16%	84%
	Adult Male	3	3	14	17	18%	82%
	Subadult Male	3	35	34	69	51%	49%
Grand Total		**10**	**58**	**154**	**212**	**27%**	**73%**
% by Food-conditioned	**All**	**5**	**90%**	**92%**	**91%**		
% by Non Food-Conditioned	**All**	**5**	**10%**	**8%**	**9%**		

Table 2.6. AIC modeling coefficients indicated factors that influence highway crossing activity within the study area northwest of Missoula, MT.

	Wald	Sig.	Exp(B)	95% Exp(B)	
				L.C.I.	U.C.I.
Darkness (present)	14.023	<0.001	6.026	2.354	15.427
Distance to Development	3.792	0.051	0.998	0.997	1.000
Distance to Cover	5.023	0.025	1.020	1.002	1.037
Stream Length in 200 m	10.226	0.001	1.001	1.001	1.002
Open Habitat	11.464	0.001	7.781	2.373	25.518
Distance to Cover x Open(1)	10.475	0.001	0.973	0.956	0.989
Distance to Cover x Dark (1)	0.436	0.509	0.997	0.998	1.006
Constant	12.262	0.000	0.110		

Scale of measurement is meters.

Table 2.7. Univariate Regression coefficients indicated variables influencing highway crossing activity of all bears within the study area northwest of Missoula, MT.

Variables	Wald	Sig.	Exp(B)	EXP(B) Lower	EXP(B) Upper	Model X2	Model Sig.
Traffic Volume	15.20	0.000	0.998	0.997	0.999	15.94	0.000
Darkness (is dark)	41.47	0.000	3.815	2.538	5.734	43.98	0.000
Average Slope	16.85	0.000	1.086	1.044	1.130	18.02	0.000
Std Deviation of Elevation	12.70	0.000	1.046	1.020	1.072	13.45	0.000
Distance to Guardrail	18.61	0.000	1.000	0.999	1.000	21.35	0.000
Distance to Guardrail End	18.80	0.000	1.000	0.999	1.000	21.68	0.000
# Developments within 200 m	0.28	0.599	1.006	0.985	1.027	0.28	0.599
Distance to Development	4.50	0.034	0.998	0.997	1.000	4.68	0.031
Road Density	1.12	0.291	1.000	1.000	1.001	1.12	0.290
Distance to Stream	11.45	0.001	0.997	0.996	0.999	12.21	0.000
Stream Density	22.96	0.000	1.002	1.001	1.002	24.21	0.000
Distance to Stream Crossing	18.30	0.000	0.999	0.999	1.000	20.01	0.000
% Cover	31.44	0.000	1.000	1.000	1.000	34.59	0.000
Distance to Cover	21.02	0.000	0.991	0.987	0.995	30.92	0.000

Scale of measurement is meters.

Table 2.8. Stepwise Modeling coefficients indicated factors influencing black bear crossing activity within the study area northwest of Missoula, MT.

	Wald	df	Sig	Exp(B)	95% Exp(B)	
					L.C.I.	U.C.I.
Darkness (present)	44.61	1	0.000	5.07481	3.15070	8.17395
Distance to Development	4.47	1	0.034	0.99811	0.99635	0.99986
Distance to Stream Crossing	9.89	1	0.002	0.99940	0.99903	0.99978
% Cover within 200 m	0.55	1	0.459	0.99999	0.99997	1.00002
Open Habitat (1)	2.3325	1	0.127	0.33766	0.08380	1.36053
%Cover x Open Habitat (1)	19.42	1	0.000	1.00006	1.00004	1.00010
Constant	0.02	1	0.896	0.91151		

Scale of measurement is meters.

Table 2.9. A 3-fold cross-validation process using Spearman-Rank tests was used to assess the relative performance of AIC and stepwise models for predicting variables influencing crossing activity.

Correlation Coefficients: Spearman's rho	**Set1**	**Set2**	**Set3**	**Average**
a) AIC Model Coefficient	0.857	0.642	0.750	0.964
a) AIC Model Significance (2-tailed)	0.014	0.119	0.052	<0.000
b) Stepwise Model Coefficient	0.958	0.905	0.934	1.00
b) Stepwise Model Significance (2-tailed)	0.000	0.002	0.0001	<0.000
c) Food-Conditioning Stepwise Model Coefficient	0.905	0.810	0.976	0.952
c) Food-Conditioning Model Significance (2-tailed)	0.002	0.015	0.000	<0.000

Table 2.10. Univariate logistic regression coefficients indicated variables influencing roadkill occurrence within the study area northwest of Missoula, MT.

Variables (scale = 100's of meters)	Wald	Sig	Exp(B)	LCI	UCI	-2LL	Model X^2	Model Sig
Significant Variables:								
Distance to Cover	5.354	0.021	0.306	0.113	0.835	92.007	13.351	<0.001
% COVER (m^2)	6.098	0.014	1.000	1.000	1.000	98.722	6.636	0.010
Distance to Stream Crossing	8.548	0.003	0.922	0.874	0.974	93.275	12.084	0.001
Stream Length in 200 m	6.102	0.014	1.257	1.048	1.507	98.367	6.991	0.008
OPENHAB(1)	3.944	0.047	0.346	0.122	0.986	101.192	4.166	0.041
OPENHAB(1)	Pearson Chi-Square = 4.094, df = 1, p = .043							
Insignificant Variables:								
Distance to Guardrail	3.411	0.065	0.978	0.955	1.001	101.63	3.73	0.053
Distance to Guardrail End	3.448	0.063	0.977	0.954	1.001	101.58	3.78	0.052
Distance to Stream	3.643	0.056	0.809	0.651	1.006	101.35	4.005	0.045
# development points in 200 m	1.727	0.189	1.069	0.968	1.180	103.51	1.850	0.173
Distance to Development	1.334	0.248	0.743	0.448	1.230	103.97	1.386	0.239
Road Length within 200m	0.449	0.503	0.955	0.835	1.092	104.9	0.454	0.501
Mean slope	1.508	0.219	1.079	0.956	1.218	103.77	1.590	0.207
Standard Deviation of Elevation	0.671	0.413	1.035	0.953	1.126	104.67	0.687	0.407

FIGURES

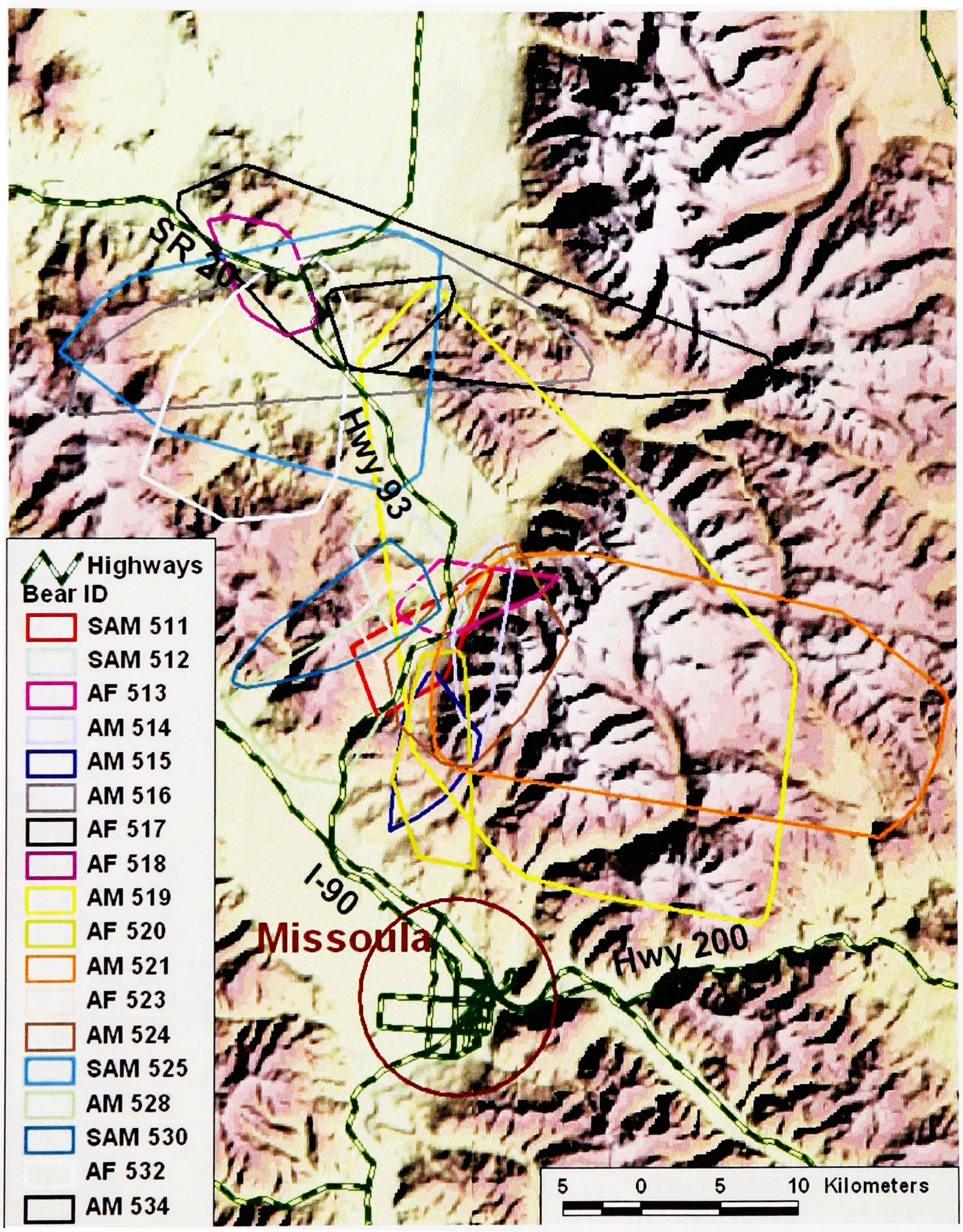

Figure 2.1. Map of 100% minimum convex polygons of individual black bears for the 2002 (August – October, 511-516, 518), 2003 (May – October, 519-534) or combined (2002 and 2003, 517) field seasons on the Flathead Indian Reservation, located northwest of Missoula, MT.

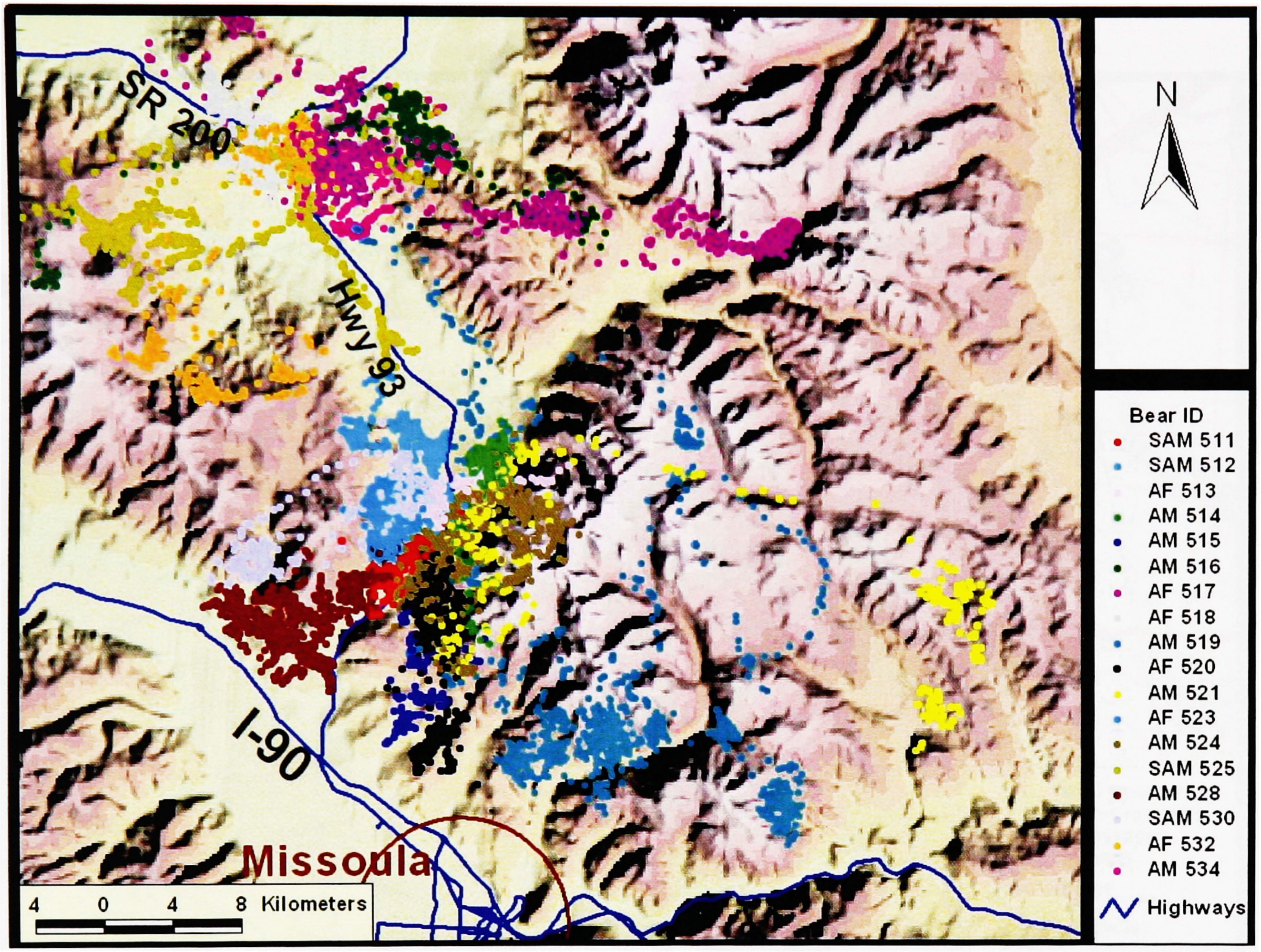

Figure 2.2. Map of black bear (*n*= 18) locations (*n* = 31,780) for the 2002 (August – October, 511-516, 518) , 2003 (May – October, 519-534) or combined (2002 and 2003, 517) field seasons on the Flathead Indian Reservation, located northwest of Missoula, MT. Colors denote individual bears where subadult male = SAM, adult male = AM, adult female = AF.

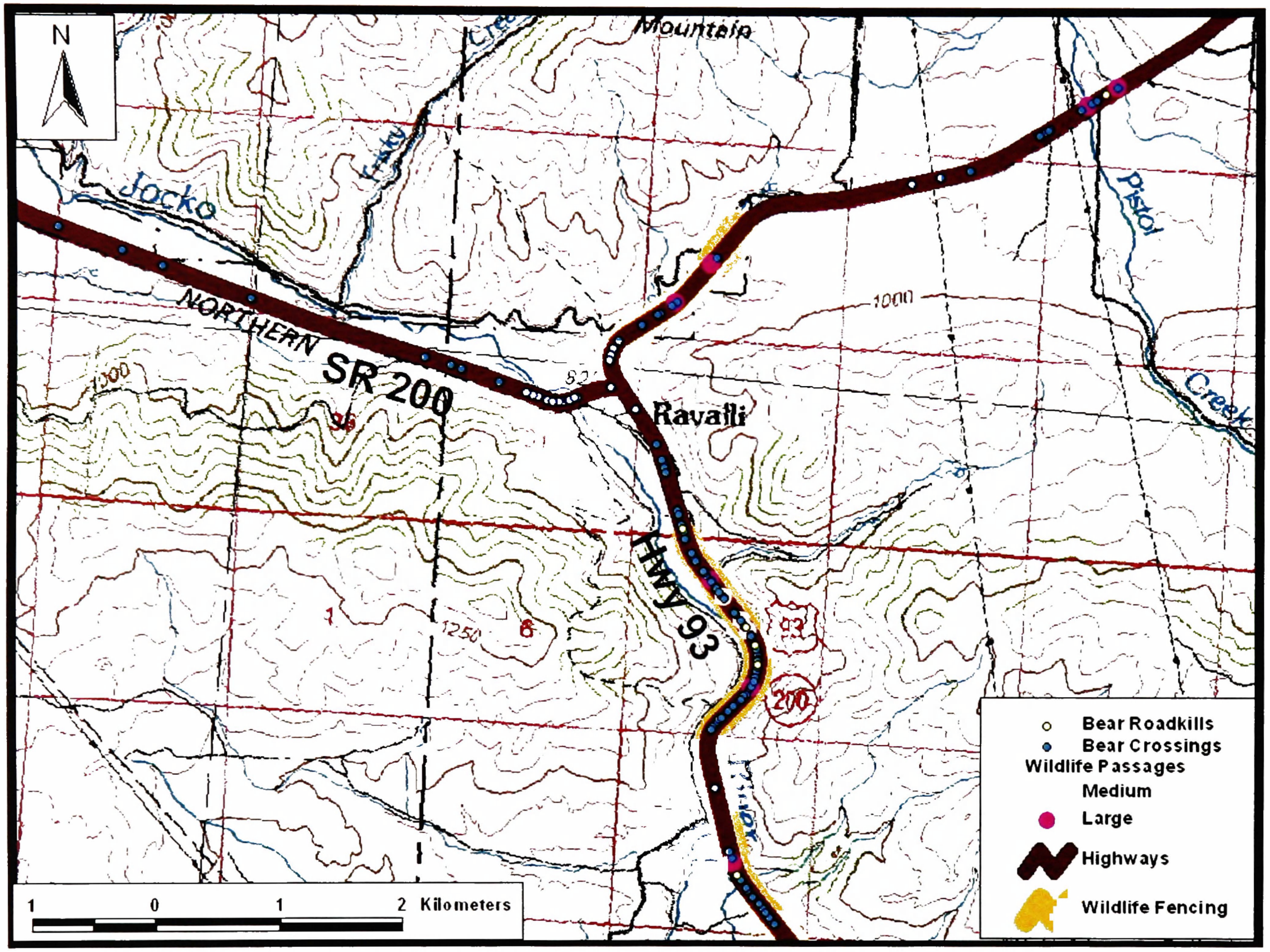

Figure 2.3. Location of black bear highway crossings, roadkills, and wildlife passages along Highway 93 on the Flathead Indian Reservation near Ravalli, MT.

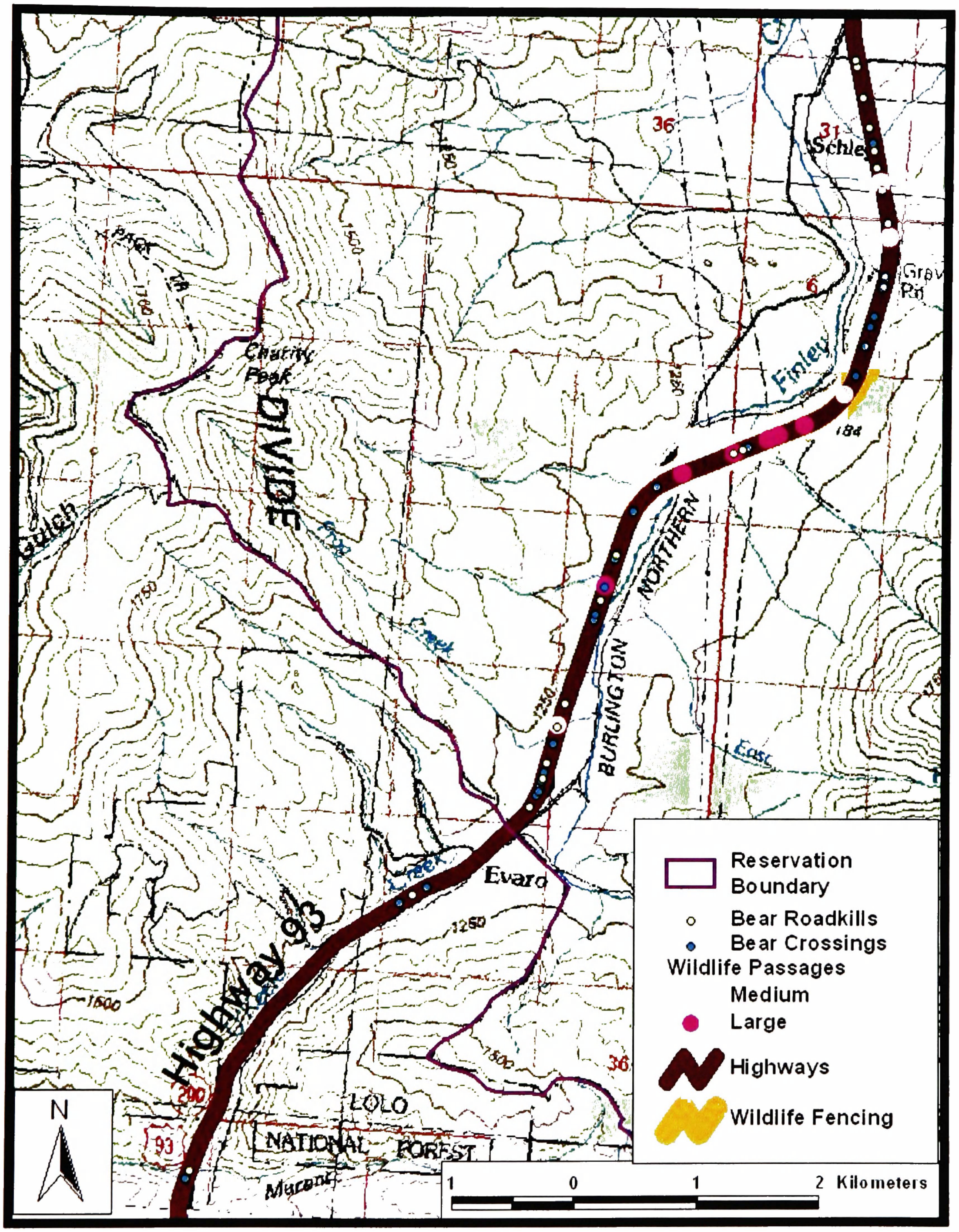

Figure 2.4. Location of black bear highway crossings, roadkills, and wildlife passages along Highway 93 on the Flathead Indian Reservation near Evaro, MT.

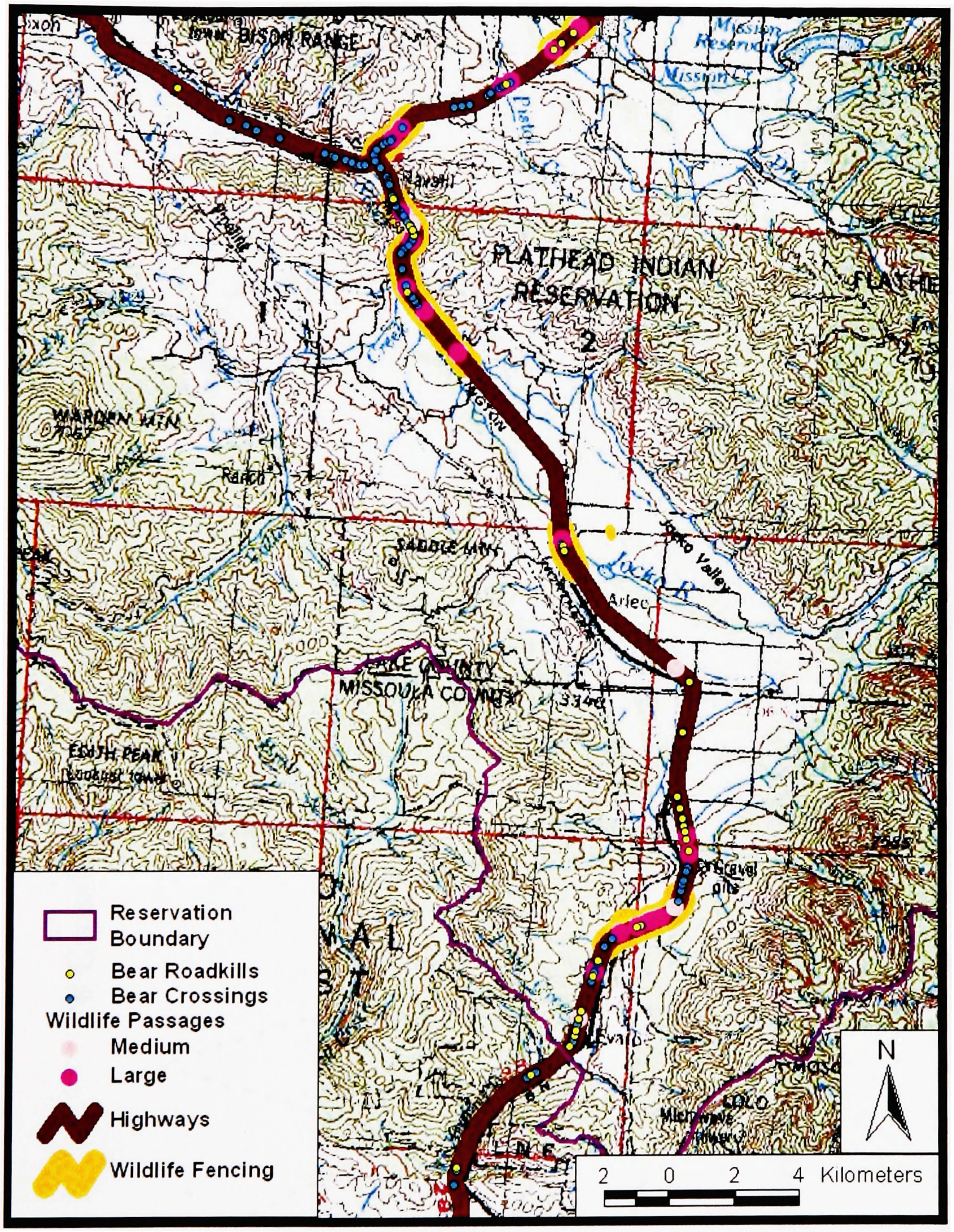

Figure 2.5. Location of all black bear highway crossings, roadkills, and wildlife passages along Highway 93 between Evaro Hill and St. Ignatius on the Flathead Indian Reservation, MT.

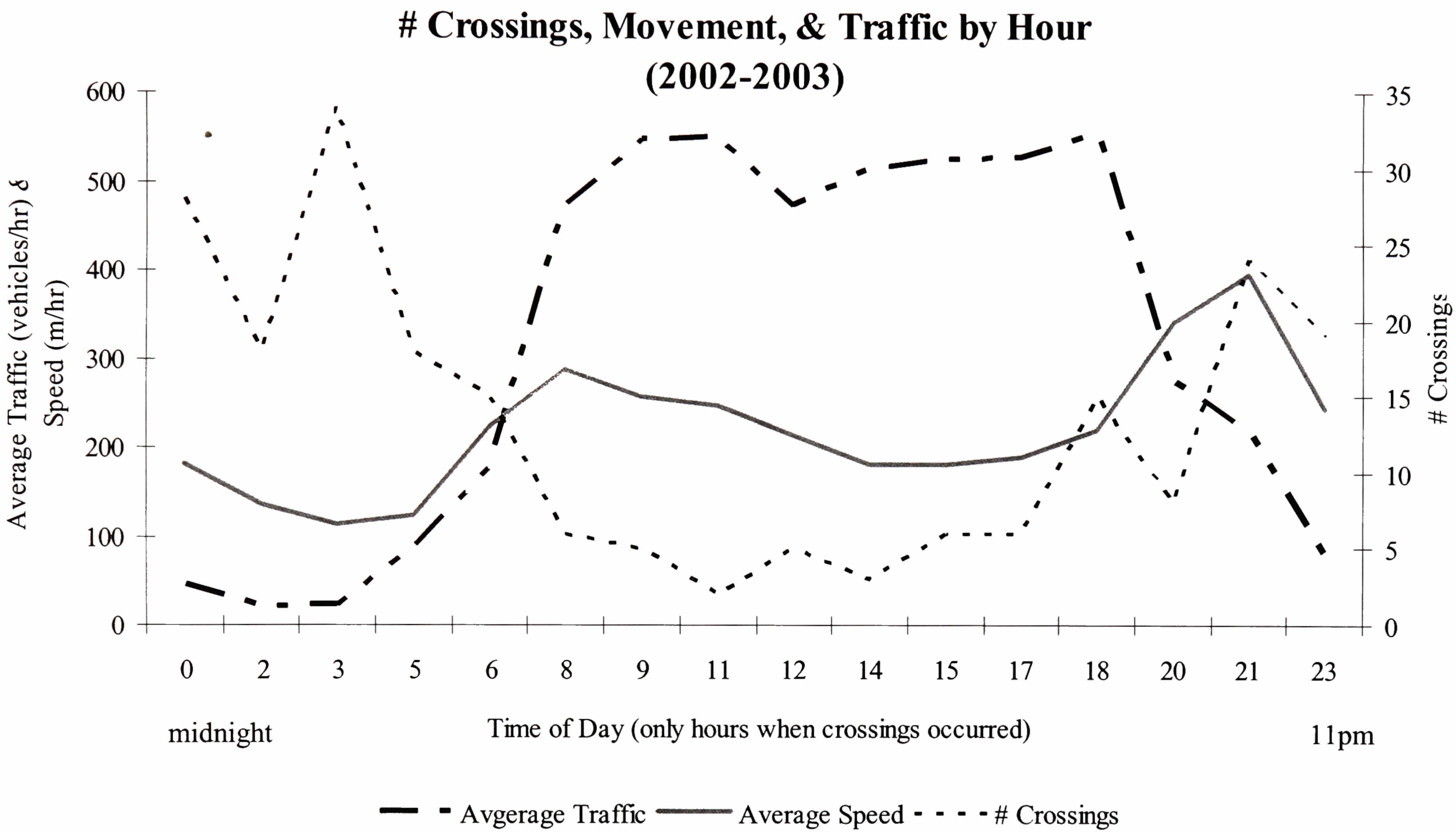

Figure 2.6. Number of black bear crossings, traffic volume during crossing events, and average speed of movement (m/hour), 2002 – 2003, northwest of Missoula, MT.

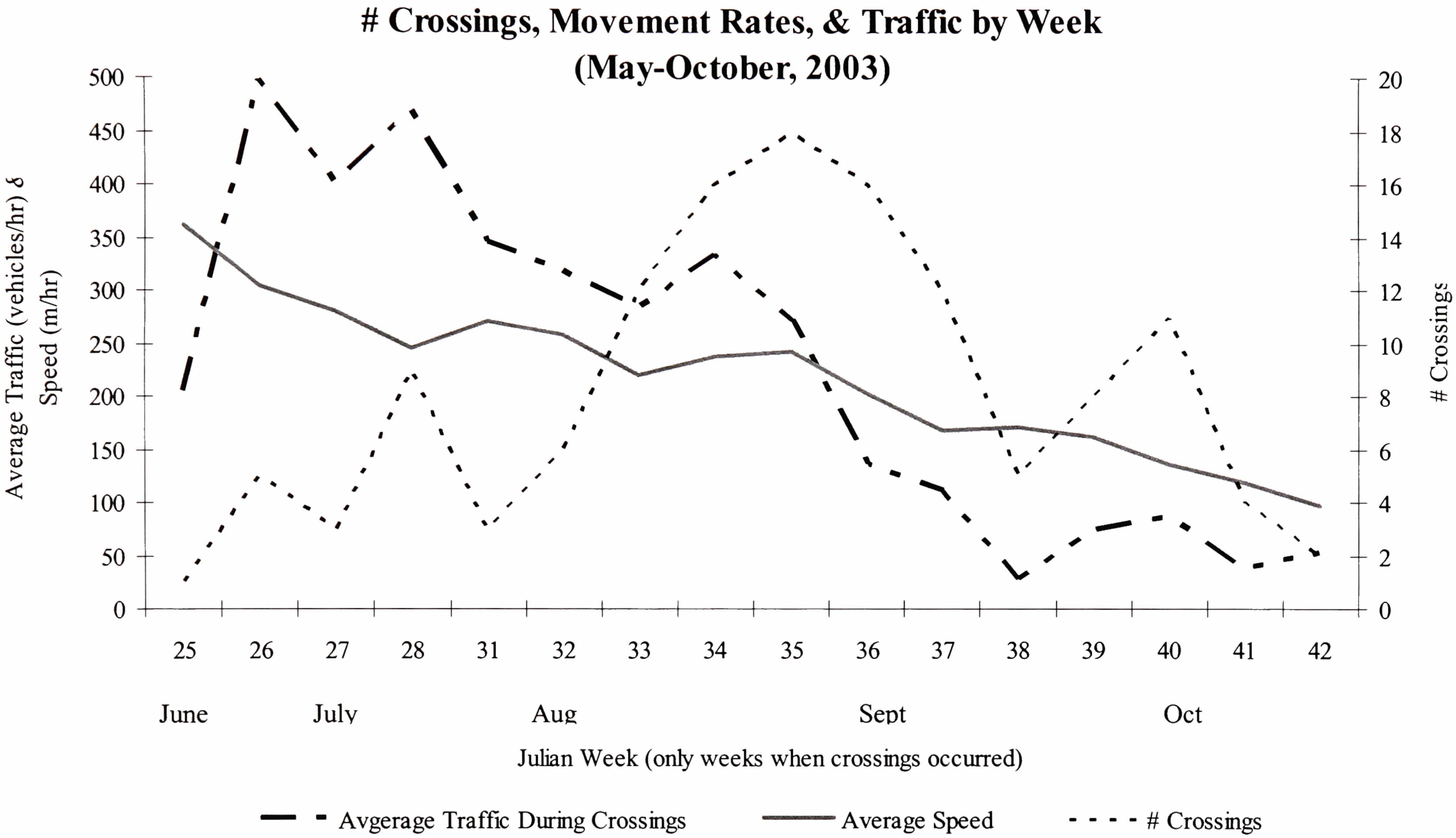

Figure 2.7. Number of black bear crossings, traffic volume during crossing events, and average speed of movement (m/hour), May – October 2003, northwest of Missoula, MT. Julian weeks are successive weeks of the year, where julian week 25 = the 3rd week in June.

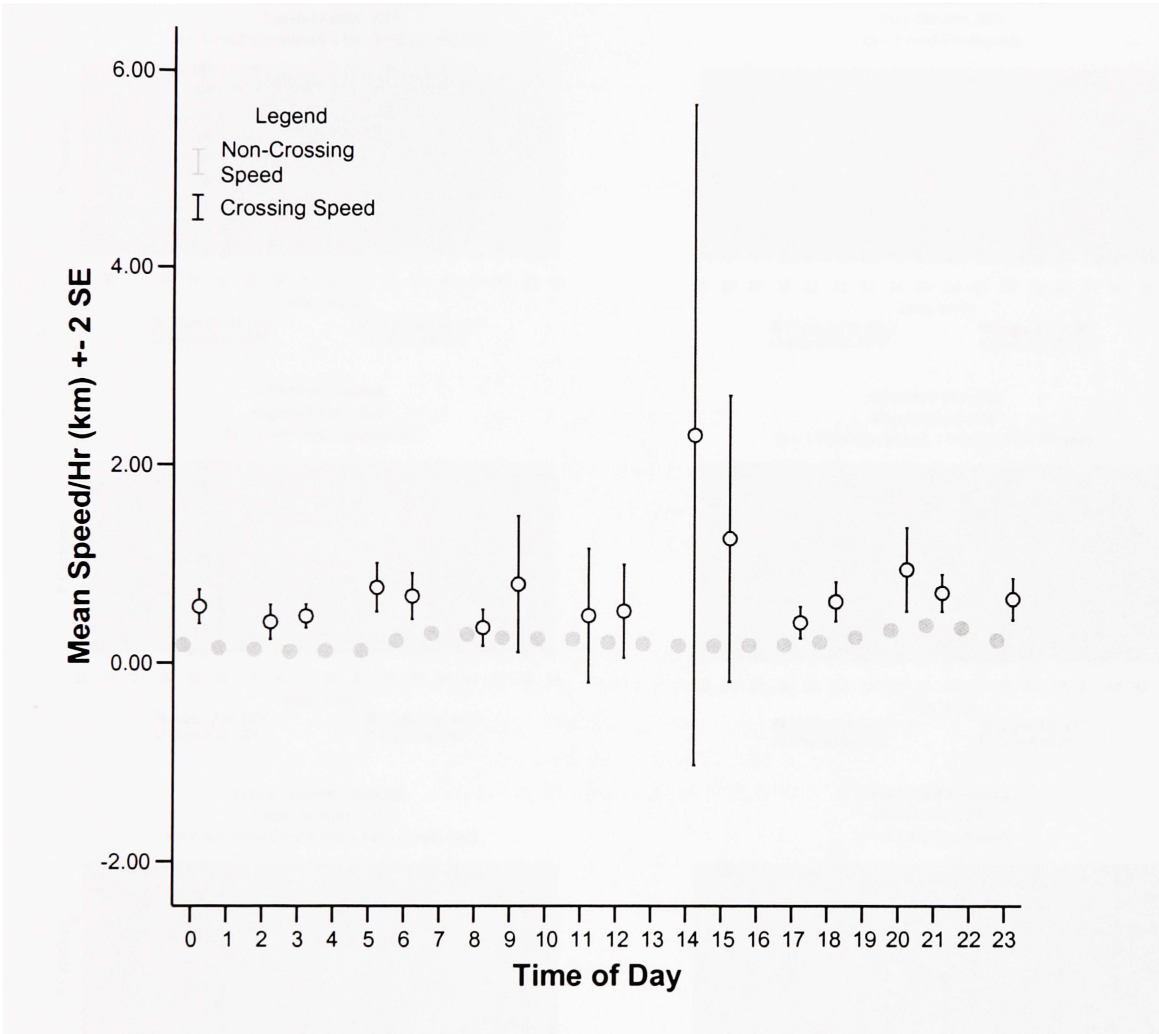

Figure 2.8. Mean speed of movement during crossings versus mean speed of movement when not crossing for each specific hour of the day. Error bars for non-crossing speeds are displayed, but too small to be seen due to the lack of variation in this extremely large data set (>30,000 locations).

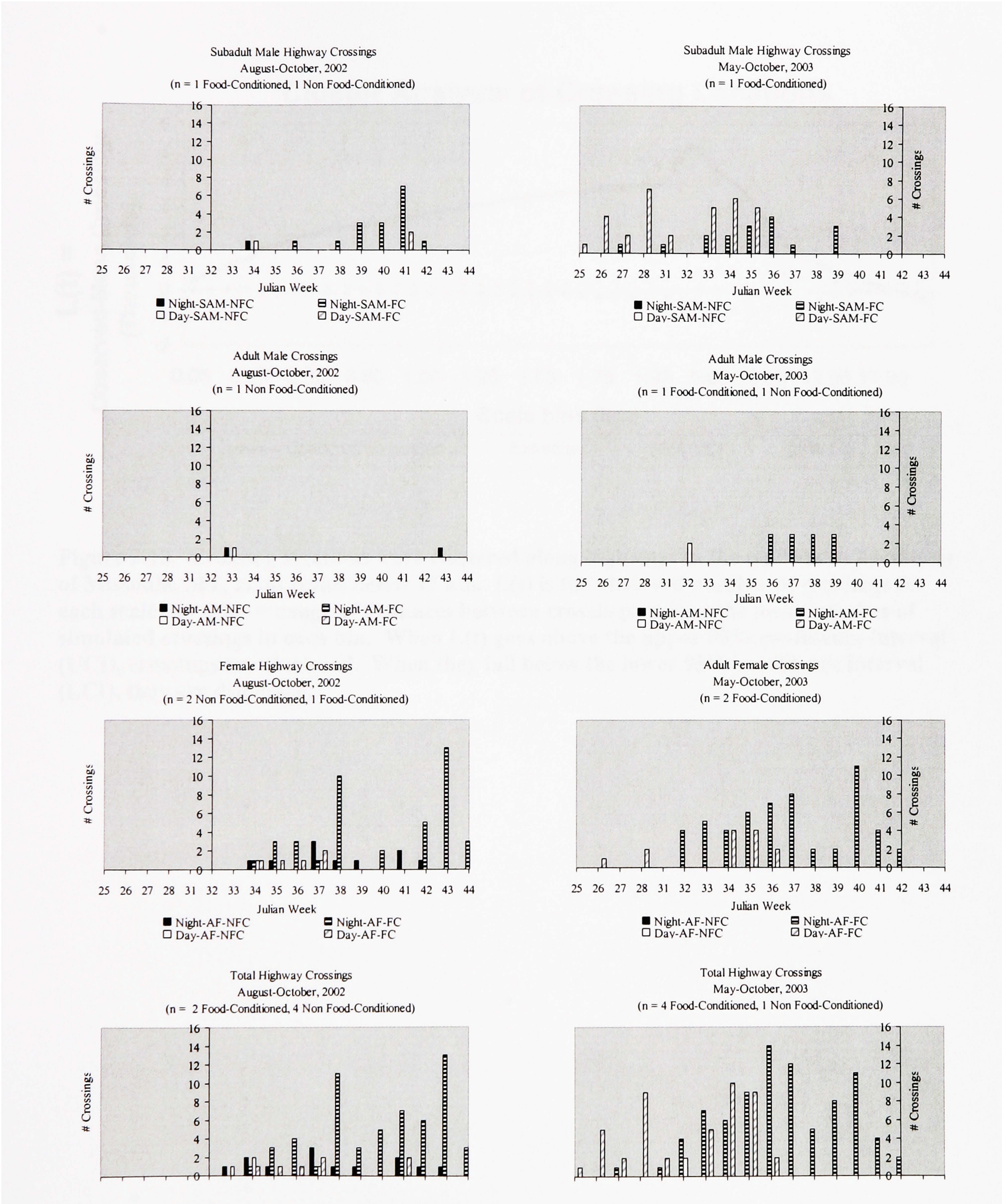

Figure 2.9. Crossings by food-conditioning, age-sex class, week, and year, where: FC = food-conditioned bear; NFC = non food-conditioned bear; AM = adult male; AF = adult female, and SAM = subadult male. The y-axis crosses the x-axis at start (2002) or end (2003) of data collection.

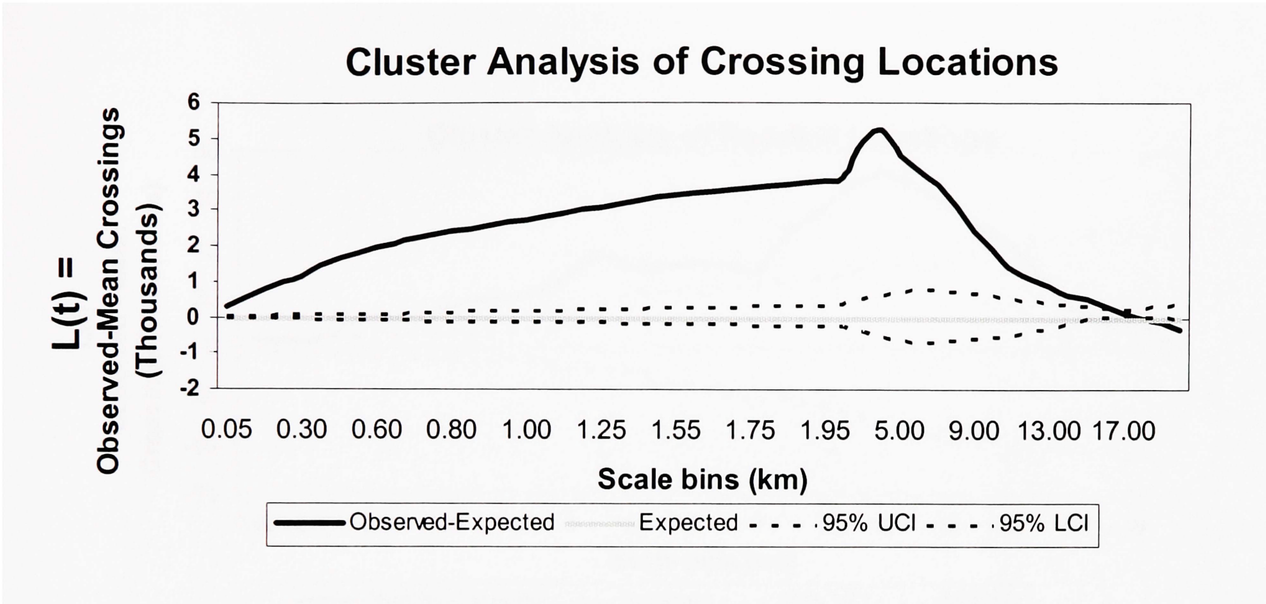

Figure 2.10. Crossing locations were clustered along highways in the study area northwest of Missoula, MT, at all scales below 17 km. L(t) is the observed number of crossings for each scale bin (bins = range of distances between crossings) minus the mean number of simulated crossings in each bin. When L(t) goes above the upper 95% confidence interval (UCI), crossings are clustered. When they fall below the lower 95% confidence interval (LCI), they are dispersed.

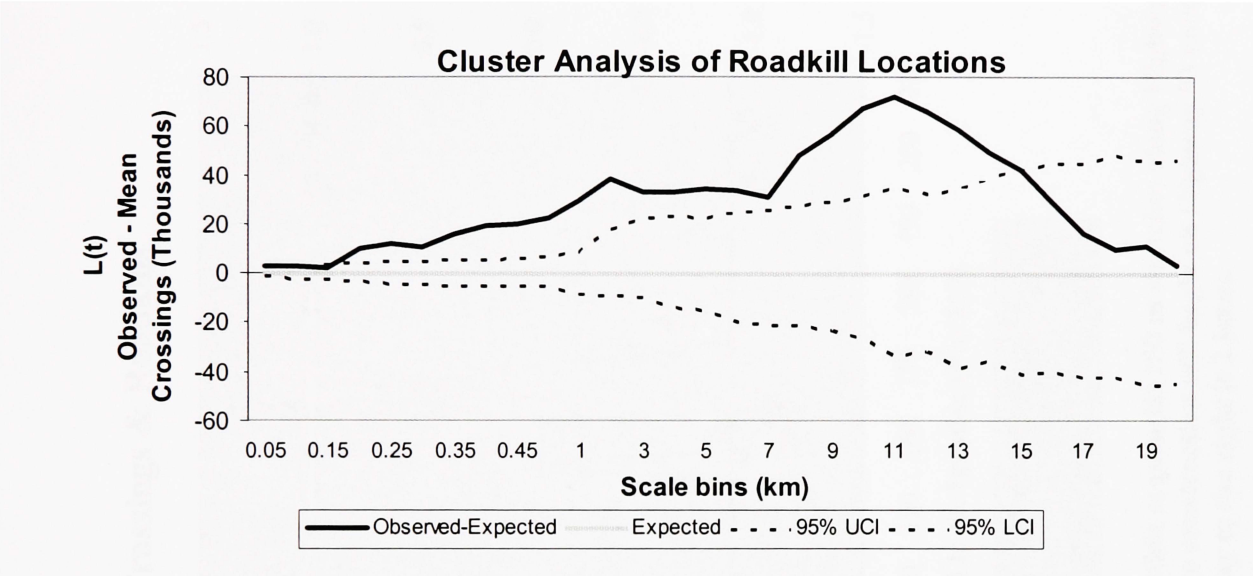

Figure 2.11. Roadkill locations were clustered between 0.20 km and 15 km along Highway 93 within the study area northwest of Missoula, MT. L(t) is the observed number of crossings for each scale bin (bins = range of distances between crossings) minus the mean number of simulated crossings in each bin. When L(t) goes above the upper 95% confidence interval (UCI), crossings are clustered. When they fall below the lower 95% confidence interval (LCI), they are dispersed.

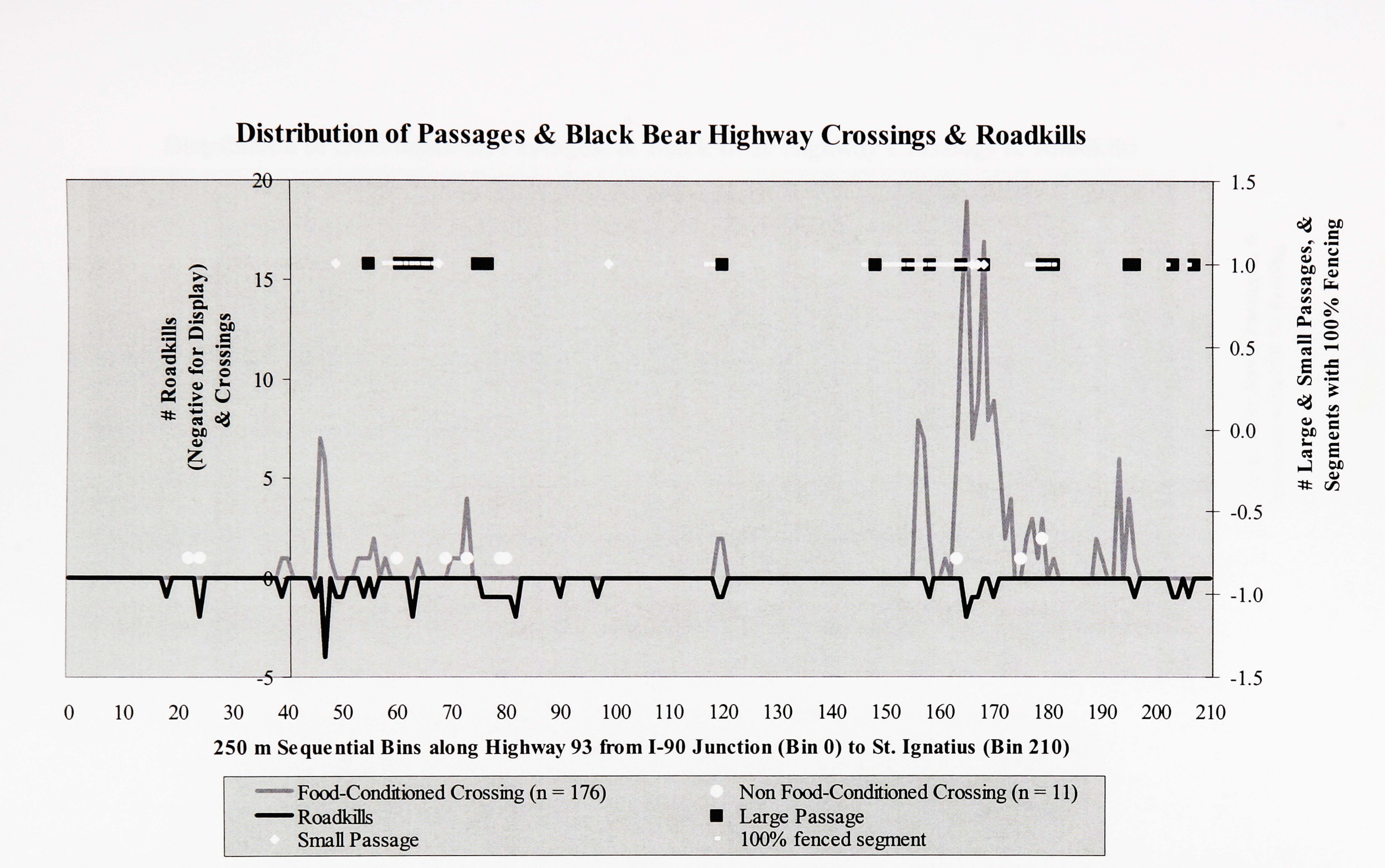

Figure 2.12. The number of crossings, roadkills, wildlife passages, and fencing within sequential 250 m stretches along Highway 93 from I-90 Junction. (Bin 1) to St. Ignatius (Bin 210). The y-axis crosses the x-axis where construction will begin on Highway 93 northwest of Missoula. The highway to the left of the y-axis is currently 4 lanes and the highway to the right is 2 lanes.

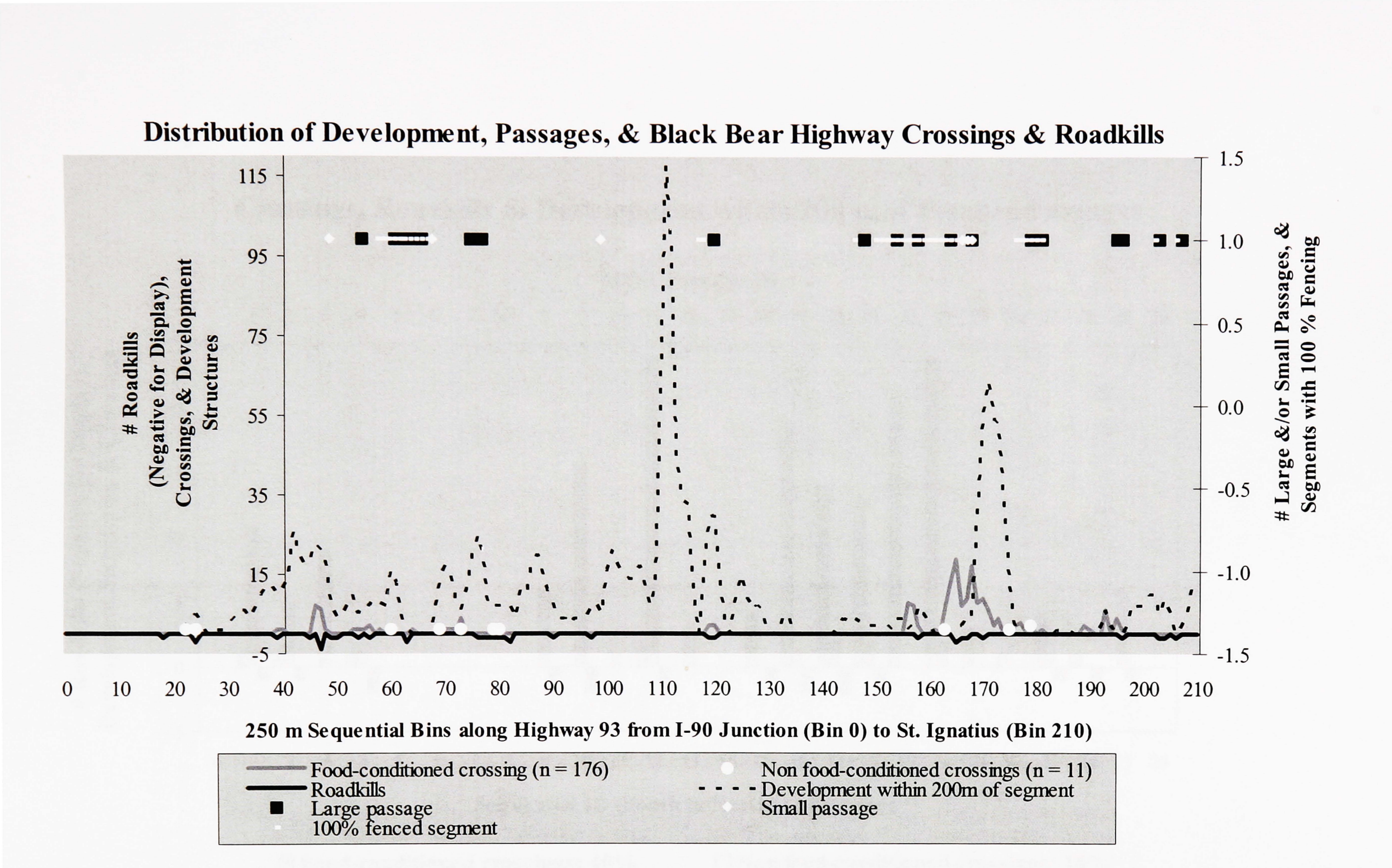

Figure 2.13. Development structures, crossings, roadkills, wildlife passages, and fencing within sequential 250 m stretches along Highway 93 from I-90 Junction (Bin 1) to St. Ignatius (Bin 210). The y-axis crosses the x-axis where construction will begin on Highway 93 northwest of Missoula. The highway to the left of the y-axis is currently 4 lanes and the highway to the right is 2 lanes.

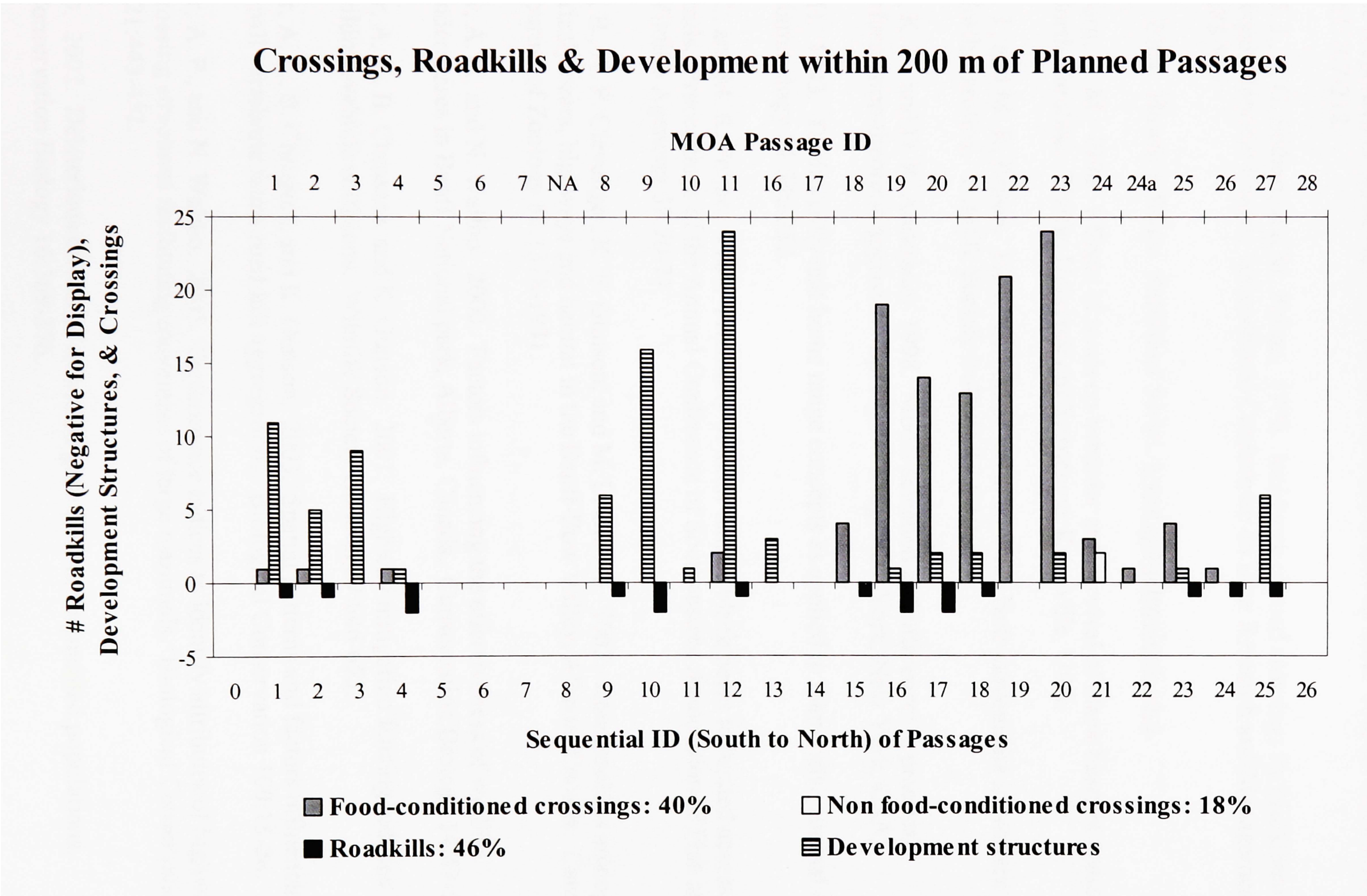

Figure 2.14. Amount of development, crossings, and roadkills within 200 m of planned locations of wildlife passages.

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CHAPTER III:

Spatial Use Patterns Relative to Highways: Black Bears in Western Montana

ABSTRACT

While several studies have measured black bear (*Ursus americanus*) response to roads or highways, none used highly accurate GPS technology to do so or accounted for possible temporal or behavioral influences on the use of areas adjacent to highways. My primary objective was to evaluate whether the highway and its associated development created a disturbance zone for different classes of black bears. I compared the location of kernel home ranges of black bears to the location of the highway to ascertain if home range placement relative to the highway differed by age-sex class and level of habituation or food-conditioning. I analyzed whether bears used distance isopleths adjacent to the highway more than, equal to, or less than expected. I then assessed whether use of these areas were influenced by levels of human activity, bear activity patterns, age-sex class, habituation, or food-conditioning.

Results indicated that kernel home ranges with 10-80% use distributions of food-conditioned and habituated bear classes were closer to the highway than home ranges of non food-conditioned and nonhabituated bears. The kernel home ranges of adult males with 10-30% use distributions were significantly farther from the highway than those of subadult males and adult females. Food-conditioned and habituated bears were closer, relative to availability, to areas within 300 m of highways when data from all activity periods were pooled. Food-conditioned and habituated bears were significantly closer, relative to availability, to areas within 600 m of the highway at night, and food-conditioned bears were significantly farther from areas 600-900 m from the highway at night. Food-conditioned and habituated bears were also closer to

the area within 300 m of the highway, relative to availability, than non food-conditioned and nonhabituated bears. Mean distances of non food-conditioned and nonhabituated bears to the areas within 600 m of the highway were significantly farther than food-conditioned and habituated bears. Food-conditioned and habituated bears centered their home ranges on or near the highway and used areas adjacent to the highway and its associated human developments more than expected, while non food-conditioned and nonhabituated bears placed their home ranges farther from the highway, so that areas adjacent to the highway were not as available to be used.

INTRODUCTION

Highways affect the ecological processes of wildlife up to 1000 m from roadsides (Forman and Deblinger 2000). However, current knowledge of how roads and highways influence placement of black bear home ranges and the use of areas adjacent to transportation systems is incomplete and somewhat contradictory (Beringer et al. 1990). Carr and Pelton (1984) found that black bears crossed unpaved roads often and frequently used areas adjacent to roads. In contrast, Kasworm and Manley (1990) found that black bears use areas within 274 m of unpaved open roads less than expected, that avoidance of roads increased in the fall, and that female avoidance of roadside environments was stronger than that of males. A review by Wooding and Maddrey (1994) summarized that black bear avoidance of roads (types unspecified) has ranged from 274-720 m. Other studies, however, have noted that bears may use unpaved forest roads frequently as travel lanes (Beringer 1990). Little information is available regarding the use of areas adjacent to highways. Beringer (1990) states that while black bears did not frequently cross a highway, they were located nearby, often approaching and then moving either away from or parallel to it. McGown and Eason (2001) found that black bears frequently crossed highways and did not avoid areas adjacent to highways. However, other studies reported that highways delineated home range boundaries, signifying avoidance behavior (Brody and Pelton 1989, Beringer 1990).

More studies of use of areas near unpaved roads and highways have been conducted for grizzly bears, and have consistently demonstrated the existence of disturbance zones, especially at higher traffic volumes, and around unpaved roads and highways. Some studies found that grizzly bears avoided areas adjacent to unpaved roads ranging from 100 m in spring to 914 m in the fall; yearlings used and males avoided areas directly adjacent to roads; females were willing to use areas that adult males avoided; and most selection was independent of traffic volumes (Mattson 1987, McLellan and Shackleton 1988, Wielgus et al. 2002). In contrast, Mace et al. (1996) found that grizzly bears used areas by unpaved roads greater than or equal to expected when traffic was less than 10 vehicles per day, but avoided them at greater traffic volumes; that they used areas with higher unpaved road densities more in the spring than other seasons; and they avoided areas with higher unpaved road densities in lower elevation habitats. Highway avoidance by grizzly bears also depends on traffic volumes and levels of human disturbance. Mattson (1987) found that avoidance of paved primary roads in Yellowstone National Park extends from 500 m in the spring and summer to 3 km in the fall, but that foraging behavior was generally disrupted over a much larger range. Waller and Servheen (2005) also found grizzly bears avoided areas within 500 m of highways. In contrast, Chruscz et al. (2003) found that grizzly bears, regardless of sex or habituation, used areas adjacent to low-volume highways more than expected, but also more than high-volume highways. Differences indicated by Chruscz et al (2003) may have been due to differences in topography and available resources.

Wildlife species using populated highway corridors are more likely to become habituated to people and to come into contact with human food sources in or near developed areas. However, very little information is available to describe effects of habituation or food-conditioning on bear use of areas adjacent to highways. Chruscz et al. (2003) found that habituated male grizzly bears were closer to low volume highways than habituated females or wary males or females, and Gibeau (2001) indicated that habituation may have influenced the willingness of certain young grizzly bears to cross a high-speed highway. Mattson (1987) noted that trends of highway avoidance by grizzly bears may have been confounded by food-conditioned status. A recent black bear study (Beckman and Berger 2003) pointed out that increases in human-bear conflicts were likely not due to bear population increases, but rather to a redistribution of bears across the landscape in response to human food sources, such that bears congregate in higher densities in urban-wildland interface zones where anthropogenic foods such as garbage are readily available.

It is evident that we still do not have a thorough understanding of the influence that transportation corridors have on black bears. While traditional telemetry has provided baseline data on the general trends of black bear behavior in relation to roads under various conditions, technological and logistical limitations have precluded a detailed analysis of use of areas adjacent to highways. Understanding spatial and temporal patterns of black bear use of areas adjacent to highways is integral to maintaining connectivity across highway systems. To better understand how highways and their associated developments affect black bears, we need to know not only if bears use roadside environments, but how transportation corridors influence bears in different age-sex classes and with different levels of habituation or food-conditioning. I used precise location data from GPS collars in an analysis of black bear use of a transportation corridor. My objectives were to: assess if home range placement in relation to the highway differed by age-sex class and habituation or food-conditioned status; determine if there was a disturbance zone associated with highways for all bears or for different classes of bears; and evaluate whether disturbance levels were influenced by human or bear activity periods.

STUDY AREA

I analyzed black bear movement on and near the Flathead Indian Reservation, Montana, home to the Confederated Salish and Kootenai Tribes (CSKT). Highway 93 runs north-south through the Flathead Indian Reservation, and consists of four lanes up to the southern boundary of the Reservation at the town of Evaro, where it becomes a two-lane highway (Figure 1.1, Chapter I). This highway has recently incurred a dramatic increase in traffic volumes and development. Annual mean daily traffic volumes on Highway 93 are 9008 (range 4610-13,154) vehicles/day in the Evaro area and 8062 (range 5231-11,534) vehicles/day in the Ravalli area south of Ravalli junction (Chapter II). The Montana Department of Transportation (MDOT) is widening most of Highway 93 between Evaro Hill and Polson to four lanes. This improvement will include placement of 42 wildlife crossing structures capable of providing passage across the highway to a variety of species and fencing to direct animals to these structures (Montana Department of Transportation et al. 2000).

The study area is on the southwestern edge of the Northern Continental Divide Ecosystem, and encompasses Highway 93 from Evaro Hill to St. Ignatius, as well as a short segment of State Route 200 west of Ravalli junction. The study area contains primary linkage habitat necessary to maintain connectivity between the Northern Continental Divide Ecosystem to the northeast and the Salmon-Selway Ecosystem to the southwest (Metz 1994, Servheen et al. 2001). The southern study area is characterized by almost continuous forest cover (77%) with few agricultural fields in the valley bottom; while the northern part is characterized by patchy forest cover (25%) intermixed with wide expanses of Palouse Prairie and agricultural fields. The study area is largely within the boundaries of the Reservation, but is characterized by a mixture of private, tribal, federal, and state lands. Forest cover is predominantly coniferous, but deciduous types are found along streams, irrigation ditches, and ponds, especially in the valley bottomlands. Bear foods include berries and non-native fruit trees, which are abundant near developed areas concentrated along the highway (Servheen 1983).

METHODS

Trapping, Collaring, and Monitoring

I trapped bears using Aldrich foot snares and culvert traps using standard techniques (Jonkel 1993) and outfitted them with Telonics Model 3500 GPS collars (Telonics Incorporated, Mesa, AZ, U.S.A.) programmed to collect hourly locations 24 hours a day. I conducted trapping activities within 3.2 km of the highway between 1 August and 15 August 2002 and between 15 May and 1 July 2003. I programmed collars to disengage from bears by 1 November in 2002 and 15 October in 2003. I placed greater emphasis on collaring adult bears, but collared any bear over 34 kg after a specified date. The minimum mass of 34 kg was set so that collars would not weigh more than 2.5% of the body mass of the bear. I monitored VHF beacons daily for mortality signals, and retrieved collars from the field when mortality signals were detected.

Identification of Food-conditioned Bears

Because food-conditioning and habituation appeared to be prevalent in my study area, I used a combination of several methods to identify food-conditioned and habituated bears. Bears that showed signs of previous capture were identified as potential food-conditioned bears. In 2003, when I located bears near developments, I interviewed landowners to determine if they had experienced nuisance bear activity or had seen collared bears. I collaborated with tribal wardens to identify research bears involved in nuisance activity, and compared tribal nuisance bear trap sites to bear GPS data locations. I used my knowledge of which bears were definitely food-conditioned in conjunction with patterns in the GPS data to evaluate the food-conditioned and habituated status of the other bears in the study.

Because food-conditioning is associated with human development sites, I used distance to development structure point as my primary variable of interest. I obtained aerial photographs (1998) of the highway corridor from the tribe, georeferenced the aerial photos, and downloaded georectified USGS Digital Orthoquads photos (1990) from the Montana Natural Resources Information System website (http://nris.state.mt.us/). I obtained a GIS layer of development points on the Reservation from the tribal GIS office, and digitized all additional human development sites within 2 kilometers of the highway, which was the extent to which aerial photo data was consistently available. Due to resolution issues, it was impossible to consistently differentiate between types of human developments. A human development site was therefore defined as any man-made building on the landscape. I analyzed bear GPS data locations to assess if there were any discernable differences between bears relative to movement path trajectories around human developments or the number of locations in close proximity to human developments.

I restricted analyses of bear locations in relation to human developments to the area within 2 km of highways, because that was the extent of the GIS development layer, and because 50% of bear locations occurred within this zone. I further limited my analyses to bear locations that occurred within 95% kernel home ranges to omit random or non-representative movements. I calculated the percentage of locations in this sample, per bear, that occurred within 10 m, 25 m, 50 m, 100 m, and 200 m of development structures. Because precision of GPS locations should be fairly consistent across collars, this scale of analysis provided an accurate representation of the relative distance of bears to development. I visually identified groups of bears through a cluster analysis and by graphing the relative percentage of locations per bear at each buffer width to identify similarities between known food-conditioned bears and bears of unknown status.

I classified bears as food-conditioned or habituated based on knowledge from the field, visual analysis of movement paths in GIS investigations, and a cluster analysis of distance measures from bear locations to development structures. I defined food-conditioned bears as those known to have consistently sought and received human-related foods (such as garbage or dog food) at human development sites along the highway, or those whose data patterns closely matched known food-conditioned bears. I defined habituated bears as those whose movement patterns displayed similarities to those of food-conditioned bears, but for which I was unable to directly confirm food-conditioned activity.

To assess whether these habituation classes of bears were meaningful, I used Mann-Whitney tests to evaluate the null hypothesis that there was no difference in mean percentage of points within each development buffer between classes. To assess whether these patterns carried over to a broader scale, I also calculated distance from every bear location within 2 km of the highway to the closest development structure within 2 km of the highway, and used a Mann-Whitney U test to evaluate whether there was a difference in the mean distance from all bear locations to development among habituation classes of bears. To verify that these broad patterns of use or non-use of areas adjacent to developments were consistent when considering availability, I created random locations within each bear's 95% kernel home range in proportion to the number of real locations within the home range, selected the locations that fell within 2 km of the highway, measured the distance from each random point to the closest development structure, calculated distance ratios (mean distance of real locations divided by the mean distance of random locations to development) for each bear, and used one-sample and independent t-tests, respectively, to evaluate whether mean use differed from random across all bears and whether differences existed between groups of bears.

Food-conditioned black bears have been known to shift activity periods to nocturnal hours so that foraging for anthropogenic food sources can occur with less disruption (Beckman and Berger 2003a). I graphed movement rates by time of day to explore whether differences in activity patterns existed for different habituation classes.

Home Range Placement in Relation to the Highway

Development within highway corridors is often concentrated in a linear fashion along the highway. Food-conditioned bears selecting for human food resources would therefore likely spend more time closer to the highway. Female and subadult males may select areas closer to human developments to seek refuge from dominant males (Mattson 1990). I tested the null hypotheses that no difference exists in mean distance to the highway between kernel home ranges of bears in different habituation and age-sex classes (adult male, adult female, and subadult male). I used Animal Movement extension in ArcView to construct kernel home ranges at 10 % increments up to 90 %, for a total of 9 kernel home ranges per individual. I then calculated distance from the highway to the closest edge of each home range. I partitioned data by habituation and age-sex class, and calculated the mean distance to the highway for each of the 9 kernel home range levels for each bear classification. I used a Mann-Whitney U test to evaluate whether distance of each level of kernel home range to the highway was significantly different between paired groups of bears. I used the Kruskal-Wallis H test to evaluate over-all differences in distributions among age-sex groups represented in my sample and the Mann-Whitney test to identify differences between each paired class.

Use of Distance Isopleths Adjacent to Highways

My objective was to understand if there was a disturbance zone related to highways and associated human development. To assess if a disturbance zone existed, I analyzed use of areas adjacent to highways that also fell within 95% kernel home ranges. I evaluated the extent of disturbance adjacent to highways by quantifying over-all use within specific distance isopleths (sequential buffer zones) of highways (Figure 3.1). Selection was quantified using distance ratios, defined as the mean distance from real bear locations to each isopleth divided by the mean distance of random locations to each isopleth. Because the individual bear was my sampling unit, distance ratios were calculated for each bear, and then averaged for analyses of all bears or different classes of bears. Because disturbance levels may vary depending on age, sex, habituation, or food-conditioning, I analyzed selection of distance isopleths for all bears, as well as for these different classes of bears. I used distance ratios to detect if isopleth use differed from expected when accounting for availability, and direct distance measures of real locations to isopleths to assess differences in isopleth availability between classes of bears. I partitioned the data by darkness to assess whether selection was different during high versus low hours of human and traffic activity. GPS fix success rates are lower (Figure 3.2) during times when bears are least active, such as when they are bedded down. Therefore, I also ran analyses with data partitioned by hours of high versus low GPS fix success rates to assess whether isopleth use differed when bears are more or less active.

I used Animal Movement extension in ArcView (Hooge and Eichenlaub 2000) to construct 95% kernel home ranges for each bear and selected all points within each kernel for inclusion in the analyses. I used Random Point Generator extension in ArcView (Jennes 2001) to create a random distribution of points within each bear's 95 % kernel home range such that the number of random points was equal to the number of real points in each home range. Each random point was assigned the same age-sex class and food-conditioned status of the original bear it was associated with, and a random date and time from the distribution of date-times available for that bear. I used only locations within 2 km of the highway for this analysis because points far from the highway are unlikely to be influenced by the highway and would increase data processing time without providing additional insights. The number of real locations per bear within 2 km of the highway varied from 21 to 2733. However, because I used individual bears as the sampling unit, as long as an adequate number of locations existed to calculate a representative mean distance, unequal sampling was not of concern (Connor and Plowman 2001). I measured the distance from each real and random bear location within 2km of the highway to each distance isopleth (Jenness 2002) and calculated distance ratios for each bear as the mean distance of real locations to each isopleth divided by the mean distance of random locations to each isopleth. I then categorized each location by day versus night and high versus low GPS fix. Day was defined as the time between sunrise and sunset, and night as the inverse, based on sunrise/sunset tables for Missoula, MT, available from the U.S. Naval Observatory Astronomical Applications Department (http://aa.usno.navy.mil). High versus low GPS fix was defined as the hours of day, for each individual bear, in which the mean hourly GPS fix success was higher or lower than the over-all mean GPS fix success for that bear.

I used a Hotelling's T test in a multivariate framework to evaluate the null hypotheses that 1) mean distance to isopleths was not different than random, and 2) mean distance to isopleths was not different than random relative to habituation and age-sex classes of bears. Multivariate analyses require that sample size be greater than the number of dependent variables, so I limited my analyses to 3 isopleths. Kasworm and Manly (1990) found that bears used areas within 274 m of unpaved roads less than expected, and over 50% of the development within 2 km of highways in my study area occurred within 300 m of highways. I therefore analyzed use of 3 distance isopleths adjacent to highways from 0 to 300 m (isopleth 1), 300 m to 600 m (isopleth 2), and 600 m to 900 m (isopleth 3).

I used one-sample t-tests in a univariate framework to assess whether mean distance to individual isopleths was greater than or less than expected for all bears combined and also for habituation and age-sex classes of bears. I used independent samples t-tests to determine if either distance ratios or mean distance measures differed between habituation classes of bears. I used a one-way ANOVA followed by t-tests, if appropriate, to evaluate differences among age-sex classes of bears.

RESULTS

Trapping, Collaring, and Monitoring

I collared 8 bears in 2002 and 11 bears in 2003, with one recapture in 2003. Of 18 collared bears, there were 8 adult males, 6 adult females, and 4 subadult males. Number of times individual bears were located via GPS technology (Chapter 2, Figure 2.2) varied (mean = 1774, range = 308-3898) because: the 2002 field season began later; some bears were captured earlier in the season than others; some bears died or shed their collars before programmed release dates;

and GPS fix success rates varied (mean = 70%, range = 19-90%). A total of 31,780 locations were available for analyses from the 18 collared bears combined. All but 3 bears had GPS fix success rates over 65% (Chapter 2, Table 2.2).

Identification of Food-conditioned and Habituated Bears

I classified 5 bears as food-conditioned, 2 bears as habituated, and the remaining 11 bears as wary bears. I documented 4 bears as food-conditioned through a combination of telemetry tracking, landowner interviews, and because they were trapped by tribal wardens after involvement in nuisance activity. The 5th food-conditioned bear was classified by a combination of tracking as well as GIS and statistical analyses. Analysis of the relative percentage of locations in buffers around development points demonstrated that different groups existed, and that: 5 bears had a higher percentage of locations near development than other bears at most buffer levels; 11 bears had few or no locations within development buffers; and 2 bears had percentages of locations within development buffers that were located between the other groups (Figure 3.3). Cluster analyses and classification trees confirmed that bears fell primarily within 2 groups with regard to the number of locations within development buffers (Figure 3.4). While the percentage of locations near development indicated some level of habituation of bears 512 and 516, their movement paths often skirted developments, and I did not document food-conditioned activity in the field. Therefore, I statistically analyzed the data in 2 ways: 1) food-conditioned versus non food-conditioned bears, where bears 512 and 516 were grouped with the non food-conditioned bears; and 2) habituated versus nonhabituated bears, where bears 512 and 516 were grouped with food-conditioned bears and defined as habituated (Table 3.1).

The mean percentage of locations from the 5 food-conditioned bears was higher within all 5 buffer levels ($p \leq 0.004$) than the remaining 11 bears (Table 3.2). Mean percentages and significance levels were similar at all buffer levels ($p \leq 0.002$) for the habituated versus nonhabituated classification. At the 2 km analysis scale, I found that the mean distance of food-conditioned bears (mean = 418 m, SE = 5 m) to development was closer ($z = -33.611$, $p < 0.001$) than non food-conditioned bears (mean = 640 m, SE = 5). Mean distance of habituated bears (mean = 406 m, SE = 4 m) to development was closer ($z = -47.607$, $p < 0.001$) than nonhabituated bears (mean = 682 m, SE = 5 m). Distance ratios indicate that food-conditioned bears were closer to developments, relative to availability, than expected (mean = 0.775, SE = 0.060, $t_4 = -3.750$, $p = 0.020$), while non food-conditioned bear use did not differ from random (mean = 1.07, SE = 0.079, $t_{12} = 0.921$, $p = 0.375$). Distance ratios indicated that habituated bears were closer to developments, relative to availability, than expected (mean = 0.795, SE = 0.121, $t_6 = -4.472$, $p = 0.004$), while nonhabituated bear use did not differ from random (mean = 1.11, SE = 0.290, $t_{10} = 1.304$, $p = 0.222$). Food-conditioned bears were closer to development, relative to availability, than non food-conditioned bears ($t_{16} = -2.218$, $p = 0.041$), and habituated bears were closer to development, relative to availability, than nonhabituated bears ($t_{16} = -2.739$, $p = 0.015$).

Movement rates were highest during crepuscular hours for all bears, but food-conditioned and habituated bear movement rates were higher during dark hours of the morning and lower during the afternoon than non food-conditioned and nonhabituated bear movement rates (Figure 3.5).

Home Range Placement in Relation to Highways

Kernel home ranges (Figure 3.6, Table 3.3) of food-conditioned bears were closer ($p \leq 0.05$) to the highway than home ranges of non food-conditioned bears at all probability levels. Results were the same for the habituated versus nonhabituated grouping, although mean estimates had larger standard errors and the 90 % kernel home range was not different between the groups. Adult female and subadult male home ranges were closer ($p \leq 0.05$) to the highway than adult male home ranges for the 10 to 30 % kernel levels. I detected no differences between mean distances to highways of adult female versus subadult male kernel home ranges.

I evaluated possible confounding effects of food-conditioning/habituation on differences in kernel home range placement between age-sex classes. Because previous tests showed no differences between adult females and subadult males, I compared them as a group to adult males. Statistical tests showed that nonhabituated adult males (AM) are farther ($p \leq 0.05$) from the highway than nonhabituated subadult males (SAM) and adult females (AF) at the 10 and 20 percent kernel home range levels (n = 6 [AM], n = 5 [SAM + AF]), and at the 10 to 30 % kernel home range levels when grouping by food-conditioning (n = 7 [AM], n = 6 [SAM + AF]). I did not test statistical differences between habituated (n = 2) or food-conditioned (n = 1) adult males and other age-sex classes (n = 5 and 6, respectively). However, the data suggest that differences may exist among food-conditioned/habituated age-sex classes, but these differences appear to be smaller and more variable. Trends also indicate that within age-sex groups, habituated or food-conditioned animals may select home range locations closer to the highway than their nonhabituated and non food-conditioned counterparts (Figure 3.7).

Use of Distance Isopleths Adjacent to Highways

Because my unit of measurement was distance, high distance ratios indicated that real locations are farther from isopleths than random locations, and low distance ratios indicated that real locations were closer than random locations. Distance ratios and mean distance to isopleths varied by individual bears, between groupings of bears, and relative to darkness and GPS fix success (Tables 3.4, 3.5, 3.6, 3.7, 3.8).

Real Bear Isopleth Use Relative to Random Use: Multivariate Analyses

Multivariate analyses indicated that over-all isopleth use did differ from expected ($p \leq 0.05$) for certain classes of bears during certain activity periods (Table 3.9). When pooling all bear locations from all activity periods, isopleth use across all distance isopleths was only different than expected for non food-conditioned bears and subadult males. When partitioning data by activity periods, use across all isopleths was different than expected for non food-conditioned and nonhabituated bears during daytime and high GPS fix success hours only. Use did not differ from expected for any other classes of bears in any other activity periods.

Real Bear Isopleth Use Relative to Random Use: Univariate Analyses

Univariate analyses indicated that use differed ($p \leq 0.05$) from random for certain classes of bears, and that selection varied by activity period (Table 3.10). When pooling locations over all activity periods, food-conditioned and habituated bears were closer to isopleth 1 than expected. During the day, nonhabituated bears and adult males were farther from isopleth 1 than expected. At night, both habituated and food-conditioned bears were closer to isopleth 1 and 2, and food-conditioned bears were farther from isopleth 3, than expected. During high GPS fix success times (high bear movement rate hours), food-conditioned and habituated bears were closer to isopleth 1 than expected. All other classes of bears during all other activity times used all isopleths as expected.

Isopleth Use Comparisons Among Different Classes of Bears

Comparisons of distance ratios and distance measures between classes of bears indicated that some classes of bears used certain isopleths more, relative to other classes, during particular activity periods (Table 3.11). Distance ratios indicated that food-conditioned bears were closer than non food-conditioned bears to isopleth 1 for all data pooled, at night, and during both high and low GPS fix times, but were equally distant from isopleth 2 and isopleth 3. Distance measures indicated that food-conditioned bears were closer than non food-conditioned bears to isopleth 1 and isopleth 2 for all activity periods evaluated, and closer to isopleth 3 for all data pooled and during the day.

Distance ratios indicated that habituated bears were: closer than nonhabituated bears to isopleth 1 for all activity periods except low GPS fix times; closer to isopleth 2 during high GPS fix times only; and equally distant to isopleth 3 at all times. Distance measures indicated that habituated bears were: closer than nonhabituated bears to isopleth 1 for all activity periods evaluated; closer to isopleth 2 for all activity periods evaluated except daytime hours; and equally distant to isopleth 3 during all activity periods. Distance measures indicated that subadult males were closer to isopleth 2 than adult males during the day, but both distance ratios and distance measures did not indicate any differences among other age-sex groups for any isopleths or activity times.

DISCUSSION

Sample size and the confounding effects of age-sex and habituation class in this study limited my ability to detect differences among age-sex classes of bears in a in a multivariate or univariate framework. Although I limited the number of dependent variables (isopleths) to allow multivariate comparisons between groups of bears, it is likely that I did not have enough power to attain multivariate significance in most cases. Univariate tests of isopleth use also indicated few differences among age-sex classes of bears, which was likely due to the confounding effects of food-conditioning. When looking at only non food-conditioned bears, results suggested subadult males and adult females placed home ranges closer to the highway than adult males. This result concurs with studies indicating that male grizzly bears (McLellan and Shackleton 1989) and black bears (Tieje and Ruff 1983) use areas near roads less than other age-sex classes. To fully address questions of transportation corridor disturbance among age-sex classes of bears, future research should examine larger sample sizes of bears for all classes of interest.

Higher nocturnal movement rates and use of areas within 300 m of Highway 93 indicated food-conditioned bears shifted high activity periods to hours when they were less disturbed by human activity and traffic. Food-conditioned bears never used the area within 300 m of the highway less than expected. However, they were closer to this area and farther from the area 600-900 m from highways than expected at night, indicating they moved closer to the highway to actively forage when human activity and traffic volumes were low. While movement rates were highest during crepuscular hours for all bears, movement rates of food-conditioned bears were higher during dark hours of the morning and lower during the afternoon than non food-conditioned bears. My results agree with other studies that have found that food-conditioned black bears may shift activity periods to nocturnal hours so that foraging for anthropogenic food sources can occur with less disruption (Beckman and Berger 2003a).

Nonhabituated bears were more disturbed by the highway than habituated or food-conditioned bears, and areas near the highway were not as available for their use. Although distance ratios indicated that nonhabituated classes of bears did not use areas within 300 m of the highway less relative to availability except during the day, they did indicate that they were using these areas less than food-conditioned and habituated bears, even when accounting for availability. Furthermore, distance measures for most activity periods indicated that habituated bears were farther from areas within 600 m of highways than habituated and food-conditioned bears. My results are similar to findings that habituated grizzly bears used areas adjacent to highways more than wary grizzly bears (Chruszc et al. 2003). Areas adjacent to the highway were used more relative to availability by food-conditioned and habituated bears, but because nonhabituated bears chose home ranges farther from highways, areas adjacent to highways were less available for their use.

Food-conditioned and habituated bears have likely shifted their home ranges and movement patterns closer to the highway in response to human-related food sources such as garbage, livestock feed, and fruit trees. Over 50% of developments within 2 km of the highway occurred within 300 m of highways, and tests indicated that food-conditioned and habituated bears were closer to developments, relative to availability, than nonhabituated bears. While habituation to humans may be beneficial to bears in that they are able to access natural foods in proximity to human disturbance areas, if unnatural food attractants are not controlled, bears can easily become food-conditioned. Food-conditioning is not beneficial to bears because they lose their fear of humans and become aggressive, leading to increased bear-human conflicts such as property damage, livestock depredations, highway collisions, and decreased personal safety in residential areas with attractants. Removing food-conditioned bears from the population may then become a necessity, because translocating food-conditioned bears often poses too high a risk due to the likelihood of continued or increased aggression by the bear. Tribal wardens on the reservation spend approximately 90% of their time addressing bear-management issues, but little progress has been made in reducing attractant sources that cause human-bear conflicts. Indeed, cases of intentional feeding and harboring of residential wildlife are documented every year. As a result, management removals and highway mortalities alone lead to excessive mortality rates for black bears within this highway corridor.

For population connectivity across landscapes to be maintained, bears must cross highways. To cross highways, bears must first be able to approach them. If human development intensity increases within high quality bear habitat along highways, wary bears will not only lose access to valuable resources, but may not cross highways either. This research suggests that highway corridors are either more accessible to habituated and food-conditioned bears, or that bears that approach the highway often become habituated or food-conditioned. Wildlife passages are being incorporated into highway design to facilitate passage for wildlife and safety for humans, but if wildlife cannot access passages without becoming food-conditioned, the utility of these passages will be greatly diminished. While food-conditioned bears may cross highways frequently (Chapter II), they and/or their offspring will likely be removed from the population, so that true connectivity is not actually occurring.

MANAGEMENT IMPLICATIONS

Planning highway design for wildlife passage needs to occur as part of a multi-agency cooperative effort to provide landscape-level connectivity. Passages must be accessible to wildlife without putting them at risk, which means regulating development along highways. New tribal home sites should be established as communities, not as isolated residences dispersed throughout high quality bear habitat. Development should be reduced or eliminated near locations of planned wildlife passages, and centralized in general. Electric fencing around campgrounds should be used to control access of bears to areas with high conflict probabilities. Adequate cover and high quality bear habitat should be maintained or created in the vicinity of passages and extending out from the highway 300-600 m.

A comprehensive management plan to reduce anthropogenic attractant sources within the highway corridor will be necessary to assure the efficacy of passages. Bear management time and funds should focus on education and control of attractants. Multi-agency cooperative management protocols should be established for containing attractant sources and dispensing fines for non-compliance or intentionally feeding bears. Electric fencing should be required around attractants such as large dumpsters, livestock pens, orchards, or individual fruit trees. Fruit should be picked from trees immediately upon ripening and not allowed to accumulate around the base of trees. Unwanted fruit should be picked before ripening or fruit trees should be removed from residential areas. Attractant sources should be mapped and areas with high nuisance bear activity should be identified and used as focal areas for education programs and the implementation of management prescriptions. Cooperative and community-based bear management teams should be formed to facilitate communication between agencies and communities; to help disseminate the burden of reducing bear-human conflicts; and to empower community members to take leadership roles in protecting local black bear populations. Ultimately, responsibility for maintaining healthy bear populations lies with the willingness of humans to control both attractant sources and the extent and intensity of their footprint on the landscape.

TABLES

Table 3.1. Summary of the number of bears in each of 2 separate classifications: food-conditioned vs. non food-conditioned (habituated + non food-conditioned bears), and habituated vs. nonhabituated (food-conditioned + habituated versus nonhabituated bears).

	Number of Individuals			
	Adult Female	**Adult Male**	**Subadult Male**	**Total**
Classification 1:				
Non food-conditioned	4	7	2	13
Food-conditioned	2	1	2	5
Total	**6**	**8**	**4**	**18**
Classification 2:				
Nonhabituated	4	6	1	11
Habituated	2	2	3	7
Total	**6**	**8**	**4**	**18**

Table 3.2. Mean percentage of locations of black bears within buffers around development structures by habituation and food-conditioned status.

Buffer Size	Mean % Locations	SE	Mean % Locations	SE	Mann-Whitney Z	p-value
	Nonhabituated Bears (n = 11)		Habituated Bears (n = 7)			
10 m	0.000	0.000	0.010	0.004	-3.152	0.002
25 m	0.000	0.000	0.041	0.011	-3.649	<.001
50 m	0.008	0.004	0.096	0.016	-3.440	<.001
100 m	0.019	0.005	0.195	0.024	-3.490	<.001
200 m	0.063	0.017	0.388	0.047	-3.487	<.001
	Non Food-Conditioned Bears (n = 13)		Food-Conditioned Bears (n = 5)			
10 m	0.000	0.000	0.015	0.004	-4.054	<0.001
25 m	0.002	0.001	0.057	0.011	-3.352	0.001
50 m	0.014	0.006	0.116	0.009	-3.220	0.001
100 m	0.037	0.014	0.218	0.025	-3.111	0.002
200 m	0.106	0.035	0.406	0.054	-2.908	0.004

Table 3.3. Distance (m) from highways to closest kernel home range edge by individual bear ID and bear class. Study area on Flathead Indian Reservation northwest of Missoula, MT.

						Kernel Home Range Probability Level						
Bear	Age Sex	F	H	K-10	K-20	K-30	K-40	K-50	K-60	K-70	K-80	K-90
						Distance to Highways (m)						
511	SAM	1	1	133	41	0	0	0	0	0	0	0
512	SAM	0	1	276	191	117	50	0	0	0	0	0
513	AF	0	0	544	491	448	410	204	134	74	16	0
514	AM	0	0	2646	2548	2472	2403	2336	2265	2183	2058	1483
515	AM	0	0	3989	3870	3782	3700	3619	3541	3455	3325	1281
516	AM	0	1	5308	5471	4179	4026	3885	2217	1732	1412	692
517	AF	1	1	25	0	0	0	0	0	0	0	0
518	AF	0	0	1033	340	209	132	65	0	0	0	0
519	AM	0	0	14114	13758	13430	13130	12860	12550	12000	3050	0
520	AF	0	0	1962	1786	1663	1553	1451	1343	1233	1107	934
521	AM	0	0	1438	928	521	129	0	0	0	0	0
523	AF	0	0	1571	1511	1462	1414	1367	1321	476	179	31
524	AM	1	1	56	0	0	0	0	0	0	0	0
525	SAM	1	1	0	0	0	0	0	0	0	0	0
528	AM	0	0	5906	5797	5707	5628	5555	5479	1178	44	0
530	SAM	0	0	1637	1487	1359	1249	1142	1033	922	801	638
532	AF	1	1	0	0	0	0	0	0	0	0	0
534	AM	0	0	5751	5876	1428	1227	1092	976	831	620	389
	Class						Mean Distance					
F =1:Food-Conditioned				43	8	0	0	0	0	0	0	0
F = 0: Non Food-Conditioned				3552	3389	2829	2696	2583	2374	1853	970	419
H = 1: Habituated				828	815	614	582	555	317	247	202	99
H = 0: Nonhabituated				3690	3490	2953	2816	2699	2604	2032	1018	432
AM: Adult Male				4901	4781	3940	3780	3668	3379	2672	1314	481
AF: Adult Female				856	688	630	585	514	466	297	217	161
SAM: Subadult Male				512	430	369	325	285	258	231	200	160

Table 3.4. Pooled GPS locations: differences among black bears distance ratios (mean real distance/mean random distance) and distance measures (m) to isopleths.

				Mean Distances to Isopleths						Mean		
				Real Locations			Random Locations			Distance Ratios		
ID	AGESEX	FC	HAB	1	2	3	1	2	3	1	2	3
511	SAM	1	1	199	132	251	261	189	273	0.76	0.70	0.92
512	SAM	0	1	365	175	174	525	361	316	0.70	0.48	0.55
513	AF	0	0	524	287	210	683	469	362	0.77	0.61	0.58
514	AM	0	0	1348	1048	748	1332	1032	732	1.01	1.01	1.02
515	AM	0	0	1205	905	605	1282	982	682	0.94	0.92	0.89
516	AM	0	1	1213	913	616	1051	757	491	1.15	1.21	1.25
517	AF	1	1	398	307	361	557	383	325	0.71	0.80	1.11
518	AF	0	0	529	337	287	464	311	297	1.14	1.09	0.97
519	AM	0	0	814	528	281	823	591	434	0.99	0.89	0.65
520	AF	0	0	1417	1117	817	1247	947	649	1.14	1.18	1.26
521	AM	0	0	1111	837	591	610	439	383	1.82	1.91	1.54
523	AF	0	0	1001	725	510	929	662	453	1.08	1.10	1.13
524	AM	1	1	546	423	401	532	361	320	1.03	1.17	1.25
525	SAM	1	1	177	161	319	469	308	274	0.38	0.52	1.16
528	AM	0	0	752	488	322	761	528	373	0.99	0.93	0.86
530	SAM	0	0	1355	1055	755	1092	792	505	1.24	1.33	1.50
532	AF	1	1	228	222	346	425	277	273	0.54	0.80	1.27
534	AM	0	0	1123	824	534	959	676	447	1.17	1.22	1.19
Total Mean				795	583	452	778	559	422	0.97	0.99	1.06
Food-conditioned Mean				310	249	336	449	304	293	0.68	0.80	1.14
Non food-conditioned Mean				981	711	496	905	657	471	1.09	1.07	1.03
Habituated Mean				447	333	353	546	377	325	0.75	0.81	1.07
Nonhabituated Mean				1016	741	515	926	675	483	1.12	1.11	1.05
Adult Male Mean				1014	746	512	919	671	483	1.14	1.16	1.08
Adult Female Mean				683	499	422	718	508	393	0.90	0.93	1.05
Subadult Mean				524	381	375	587	413	342	0.77	0.76	1.03

FC = 1 (food-conditioned), HAB = 1 (habituated), AM (adult male), AF (adult female), SAM (subadult male)

Table 3.5. Daylight GPS locations: differences among black bear distance ratios (mean real distance/mean random distance) and distance measures (m) to isopleths.

				Mean Distances to Isopleths						Mean		
				Real Locations			Random Locations			Distance Ratios		
ID	**AGESEX**	**FC**	**HAB**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
511	SAM	1	1	266	127	190	241	178	274	1.11	0.71	0.69
512	SAM	0	1	322	146	171	550	367	302	0.59	0.40	0.57
513	AF	0	0	570	339	247	663	456	360	0.86	0.74	0.69
514	AM	0	0	1373	1073	773	1312	1012	712	1.05	1.06	1.09
515	AM	0	0	1276	976	676	1298	998	698	0.98	0.98	0.97
516	AM	0	1	1249	949	649	1040	747	485	1.20	1.27	1.34
517	AF	1	1	464	311	309	548	375	319	0.85	0.83	0.97
518	AF	0	0	581	362	277	460	307	292	1.26	1.18	0.95
519	AM	0	0	909	609	314	796	569	416	1.14	1.07	0.76
520	AF	0	0	1421	1121	821	1266	966	667	1.12	1.16	1.23
521	AM	0	0	995	727	496	597	428	374	1.67	1.70	1.32
523	AF	0	0	1014	743	534	923	659	456	1.10	1.13	1.17
524	AM	1	1	682	501	407	536	364	322	1.27	1.38	1.26
525	SAM	1	1	204	160	294	469	308	273	0.43	0.52	1.08
528	AM	0	0	725	457	294	747	514	365	0.97	0.89	0.81
530	SAM	0	0	1351	1051	751	1100	800	511	1.23	1.31	1.47
532	AF	1	1	316	235	287	425	276	270	0.74	0.85	1.06
534	AM	0	0	1184	884	588	941	662	443	1.26	1.34	1.33
Total Mean				828	598	449	773	555	419	1.05	1.03	1.04
Food-conditioned Mean				387	267	297	444	300	292	0.88	0.86	1.01
Non food-conditioned Mean				998	726	507	899	653	468	1.11	1.09	1.05
Habituated Mean				501	347	329	544	374	321	0.88	0.85	1.00
Nonhabituated Mean				1036	758	525	919	670	481	1.15	1.14	1.07
Adult Male Mean				1049	772	524	908	662	477	1.19	1.21	1.11
Adult Female Mean				728	518	412	714	507	394	0.99	0.98	1.01
Subadult Mean				536	371	351	590	413	340	0.84	0.74	0.95

FC = 1 (food-conditioned), HAB = 1 (habituated), AM (adult male), AF (adult female), SAM (subadult male)

Table 3.6. Nighttime GPS locations: differences among black bear distance ratios (mean real distance/mean random distance) and distance measures (m) to isopleths.

				Mean Distances to Isopleths						Mean		
				Real Locations			Random Locations			Distance Ratios		
ID	**AGESEX**	**FC**	**HAB**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
511	SAM	1	1	138	137	307	288	202	272	0.48	0.68	1.13
512	SAM	0	1	427	217	179	490	353	336	0.87	0.62	0.53
513	AF	0	0	475	234	171	706	483	364	0.67	0.48	0.47
514	AM	0	0	1337	1037	737	1360	1061	761	0.98	0.98	0.97
515	AM	0	0	780	480	184	1262	962	662	0.62	0.50	0.28
516	AM	0	1	1175	875	580	1067	771	500	1.10	1.13	1.16
517	AF	1	1	327	304	417	567	391	332	0.58	0.78	1.26
518	AF	0	0	478	313	298	468	315	302	1.02	0.99	0.99
519	AM	0	0	715	445	247	875	636	470	0.82	0.70	0.53
520	AF	0	0	1406	1106	806	1218	918	620	1.15	1.20	1.30
521	AM	0	0	1292	1009	741	630	456	396	2.05	2.21	1.87
523	AF	0	0	975	689	462	940	665	448	1.04	1.04	1.03
524	AM	1	1	377	327	393	525	357	318	0.72	0.91	1.24
525	SAM	1	1	140	163	355	469	308	276	0.30	0.53	1.29
528	AM	0	0	797	539	368	784	548	385	1.02	0.98	0.95
530	SAM	0	0	1362	1062	762	1080	780	496	1.26	1.36	1.54
532	AF	1	1	131	207	412	424	278	277	0.31	0.75	1.48
534	AM	0	0	1048	751	470	997	707	457	1.05	1.06	1.03
Total Mean				743	550	438	786	566	426	0.89	0.94	1.06
Food-conditioned Mean				223	228	377	455	307	295	0.48	0.73	1.28
Non food-conditioned Mean				944	674	462	914	666	477	1.05	1.02	0.97
Habituated Mean				388	319	378	547	380	330	0.62	0.77	1.16
Nonhabituated Mean				969	697	477	938	685	487	1.06	1.05	1.00
Adult Male Mean				940	683	465	938	687	493	1.04	1.06	1.00
Adult Female Mean				632	475	427	721	509	390	0.80	0.87	1.09
Subadult Mean				517	395	401	582	411	345	0.73	0.80	1.12

FC = 1 (food-conditioned), HAB = 1 (habituated), AM (adult male), AF (adult female), SAM (subadult male)

Table 3.7. High GPS fix success GPS locations: differences among black bear distance ratios (mean real distance/mean random distance) and distance measures (m) to isopleths.

				Mean Distances to Isopleths						Mean		
				Real Locations			Random Locations			Distance Ratios		
ID	AGESEX	FC	HAB	1	2	3	1	2	3	1	2	3
511	SAM	1	1	192	139	265	290	212	284	0.66	0.66	0.93
512	SAM	0	1	337	157	173	522	354	309	0.64	0.44	0.56
513	AF	0	0	511	267	186	681	470	365	0.75	0.57	0.51
514	AM	0	0	1330	1030	730	1352	1052	752	0.98	0.98	0.97
515	AM	0	0	1276	976	676	1300	1000	700	0.98	0.98	0.97
516	AM	0	1	1172	872	577	1055	760	491	1.11	1.15	1.18
517	AF	1	1	389	294	348	551	380	325	0.71	0.78	1.07
518	AF	0	0	513	336	299	460	308	295	1.11	1.09	1.01
519	AM	0	0	829	543	292	789	563	415	1.05	0.97	0.70
520	AF	0	0	1428	1128	828	1237	937	638	1.15	1.20	1.30
521	AM	0	0	936	681	468	561	399	358	1.67	1.71	1.31
523	AF	0	0	1017	743	531	916	650	448	1.11	1.14	1.18
524	AM	1	1	539	421	403	560	381	327	0.96	1.10	1.23
525	SAM	1	1	167	157	319	443	295	274	0.38	0.53	1.17
528	AM	0	0	719	460	305	753	525	375	0.96	0.88	0.81
530	SAM	0	0	1352	1052	752	1094	794	507	1.24	1.32	1.48
532	AF	1	1	213	229	370	436	280	270	0.49	0.82	1.37
534	AM	0	0	1109	810	519	970	690	465	1.14	1.17	1.12
Total Mean				779	572	447	776	558	422	0.95	0.97	1.05
Food-conditioned Mean				300	248	341	456	309	296	0.64	0.78	1.15
Non food-conditioned Mean				964	697	487	899	654	471	1.07	1.05	1.01
Habituated Mean				430	324	351	551	380	326	0.71	0.78	1.07
Nonhabituated Mean				1002	730	508	919	672	484	1.10	1.09	1.03
Adult Male Mean				989	724	496	918	671	485	1.11	1.12	1.04
Adult Female Mean				679	500	427	714	504	390	0.89	0.93	1.07
Subadult Mean				512	376	377	587	414	344	0.73	0.74	1.04

FC = 1 (food-conditioned), HAB = 1 (habituated), AM (adult male), AF (adult female), SAM (subadult male)

Table 3.8. Low GPS fix success GPS locations: differences among black bear distance ratios (mean real distance/mean random distance) and distance measures (m) to isopleths.

				Mean Distances to Isopleths						Mean		
				Real Locations			Random Locations			Distance Ratios		
ID	AGESEX	FC	HAB	1	2	3	1	2	3	1	2	3
511	SAM	1	1	207	125	235	240	172	265	0.86	0.72	0.89
512	SAM	0	1	404	200	175	530	371	326	0.76	0.54	0.54
513	AF	0	0	538	310	237	685	467	357	0.79	0.66	0.66
514	AM	0	0	1383	1083	783	1305	1005	705	1.06	1.08	1.11
515	AM	0	0	780	480	184	1262	962	662	0.62	0.50	0.28
516	AM	0	1	1256	956	656	1048	755	492	1.20	1.27	1.33
517	AF	1	1	405	319	374	563	385	325	0.72	0.83	1.15
518	AF	0	0	545	339	275	467	313	299	1.17	1.08	0.92
519	AM	0	0	784	500	260	891	649	471	0.88	0.77	0.55
520	AF	0	0	1402	1102	802	1259	959	661	1.11	1.15	1.21
521	AM	0	0	1296	1003	722	672	490	413	1.93	2.05	1.75
523	AF	0	0	983	704	487	943	675	457	1.04	1.04	1.07
524	AM	1	1	556	426	399	502	340	313	1.11	1.25	1.27
525	SAM	1	1	188	166	319	496	322	274	0.38	0.51	1.16
528	AM	0	0	818	544	356	780	534	369	1.05	1.02	0.97
530	SAM	0	0	1362	1062	763	1088	788	500	1.25	1.35	1.52
532	AF	1	1	246	214	318	413	274	277	0.60	0.78	1.15
534	AM	0	0	1142	843	555	944	658	425	1.21	1.28	1.31
Total Mean				794	576	439	783	562	422	0.98	0.99	1.05
Food-conditioned Mean				320	250	329	443	299	291	0.73	0.82	1.13
Non food-conditioned Mean				976	702	481	914	664	472	1.08	1.06	1.02
Habituated Mean				466	344	354	542	374	324	0.80	0.84	1.07
Nonhabituated Mean				1003	725	493	936	682	484	1.10	1.09	1.03
Adult Male Mean				1002	729	489	926	674	481	1.13	1.15	1.07
Adult Female Mean				687	498	416	722	512	396	0.90	0.92	1.03
Subadult Mean				540	388	373	589	413	341	0.81	0.78	1.03

FC = 1 (food-conditioned), HAB = 1 (habituated), AM (adult male), AF (adult female), SAM (subadult male)

Table 3.9. Multivariate analyses of real versus random use of isopleths adjacent to highways by bear class and activity period.

Activity Period	Bear Class	*n*	df	Error df	F	Sig.
All Periods	All Bears	18	3	15	0.997	0.421
	Food-conditioned	5	3	2	4.659	0.182
	Non food-conditioned	13	3	10	3.811	0.047
	Habituated	7	3	4	2.829	0.170
	Nonhabituated	11	3	8	3.238	0.082
	Adult Male	8	3	5	0.880	0.511
	Adult Female	6	3	3	1.548	0.346
	Subadult Male	4	3	1	529.259	0.032
Day	All Bears	18	3	15	1.304	0.310
	Food-conditioned	5	3	2	1.694	0.392
	Non food-conditioned	13	3	10	6.372	0.011
	Habituated	7	3	4	1.837	0.281
	Nonhabituated	11	3	8	4.311	0.044
	Adult Male	8	3	5	1.460	0.331
	Adult Female	6	3	3	0.501	0.708
	Subadult Male	4	3	1	4.146	0.343
Night	All Bears	18	3	15	0.765	0.531
	Food-conditioned	5	3	2	7.705	0.117
	Non food-conditioned	13	3	10	1.490	0.276
	Habituated	7	3	4	3.137	0.149
	Nonhabituated	11	3	8	1.464	0.296
	Adult Male	8	3	5	1.201	0.399
	Adult Female	6	3	3	2.656	0.222
	Subadult Male	4	3	1	1.543	0.520
High GPS Fix	All Bears	18	3	15	0.727	0.551
	Food-conditioned	5	3	2	3.196	0.247
	Non food-conditioned	13	3	10	4.684	0.027
	Habituated	7	3	4	3.521	0.128
	Nonhabituated	11	3	8	3.777	0.059
	Adult Male	8	3	5	0.896	0.504
	Adult Female	6	3	3	1.693	0.338
	Subadult Male	4	3	1	22.879	0.152
Low GPS Fix	All Bears	18	3	15	0.471	0.707
	Food-conditioned	5	3	2	3.790	0.216
	Non food-conditioned	13	3	10	1.936	0.188
	Habituated	7	3	4	2.024	0.253
	Nonhabituated	11	3	8	1.524	0.281
	Adult Male	8	3	5	1.223	0.393
	Adult Female	6	3	3	1.601	0.354
	Subadult Male	4	3	1	8.129	0.251

Table 3.10. Univariate analyses of real versus random use of isopleths adjacent to highways by bear class and activity period.

Activity Period	Bear Class	*n*	Isopleth 1 (0-300 m)	Isopleth 2 (300-600 m)	Isopleth 3 600-900 m)
All Periods	All Bears	18	=	=	=
	Food-conditioned	5	<	=	=
	Non food-conditioned	13	=	=	=
	Habituated	7	<	=	=
	Nonhabituated	11	=	=	=
	Adult Male	8	=	=	=
	Adult Female	6	=	=	=
	Subadult Male	4	=	=	=
Day	All Bears	18	=	=	=
	Food-conditioned	5	=	=	=
	Non food-conditioned	13	=	=	=
	Habituated	7	=	=	=
	Nonhabituated	11	>	=	=
	Adult Male	8	>	=	=
	Adult Female	6	=	=	=
	Subadult Male	4	=	=	=
Night	All Bears	18	=	=	=
	Food-conditioned	5	<	<	>
	Non food-conditioned	13	=	=	=
	Habituated	7	<	<	=
	Nonhabituated	11	=	=	=
	Adult Male	8	=	=	=
	Adult Female	6	=	=	=
	Subadult Male	4	=	=	=
High GPS Fix	All Bears	18	=	=	=
	Food-conditioned	5	<	=	=
	Non food-conditioned	13	=	=	=
	Habituated	7	<	=	=
	Nonhabituated	11	=	=	=
	Adult Male	8	=	=	=
	Adult Female	6	=	=	=
	Subadult Male	4	=	=	=
Low GPS Fix	All Bears	18	=	=	=
	Food-conditioned	5	=	=	=
	Non food-conditioned	13	=	=	=
	Habituated	7	=	=	=
	Nonhabituated	11	=	=	=
	Adult Male	8	=	=	=
	Adult Female	6	=	=	=
	Subadult Male	4	=	=	=

> (farther than expected), < (closer than expected), = (as expected), significance set at $p \leq 0.05$

Table 3.11. Univariate analyses of differences in isopleth use between classes of bears during activity periods.

	Isopleth1 Distance Ratio	Isopleth 1 Distance Measure	Isopleth 2 Distance Ratio	Isopleth 2 Distance Measure	Isopleth 3 Distance Ratio	Isopleth 3 Distance Measure
All Data						
FC vs. NFC	FC < NFC	FC < NFC	=	FC < NFC	=	FC < NFC
H vs. NH	H < NH	H < NH	=	H < NH	=	=
Day						
FC vs. NFC	=	FC < NFC	=	FC < NFC	=	FC < NFC
H vs. NH	H < NH	H < NH	=	=	H < NH	=
AM vs. SAM*	=	=	SAM<AM	=	=	=
Night						
FC vs. NFC	FC < NFC	FC < NFC	=	FC < NFC	=	=
H vs. NH	H < NH	H < NH	=	H < NH	=	=
High GPS Fix						
FC vs. NFC	FC < NFC	FC < NFC	=	FC < NFC	=	=
H vs. NH	H < NH	H < NH	H < NH	H < NH	=	=
Low GPS Fix						
FC vs. NFC	FC < NFC	FC < NFC	=	FC < NFC	=	=
H vs. NH	=	H < NH	=	H < NH	=	=

*There were no significant differences in distance ratios or distance measures for any other age-sex class comparison for any distance isopleth

FC (food-conditioned), NFC (non food-conditioned), H (habituated), NH (nonhabituated)
AM (adult male), SAM (subadult male)
> (farther than expected), < (closer than expected), = (as expected), significance set at $p \leq 0.05$

Figure 3.1. Map of sequential distance isopleths adjacent to highways on the Flathead Indian Reservation northwest of Missoula, MT.

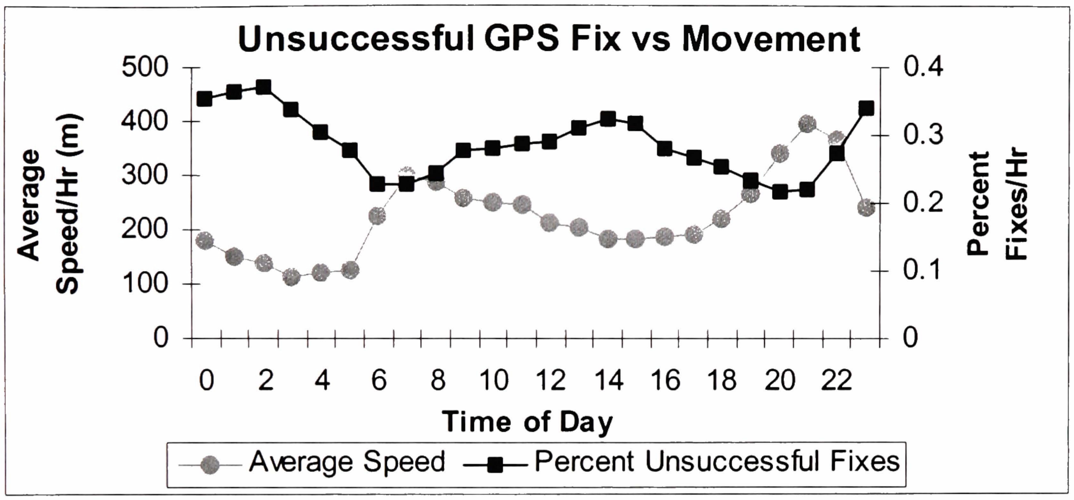

Figure 3.2. Comparison of GPS fix success to average movement rates by time of day.

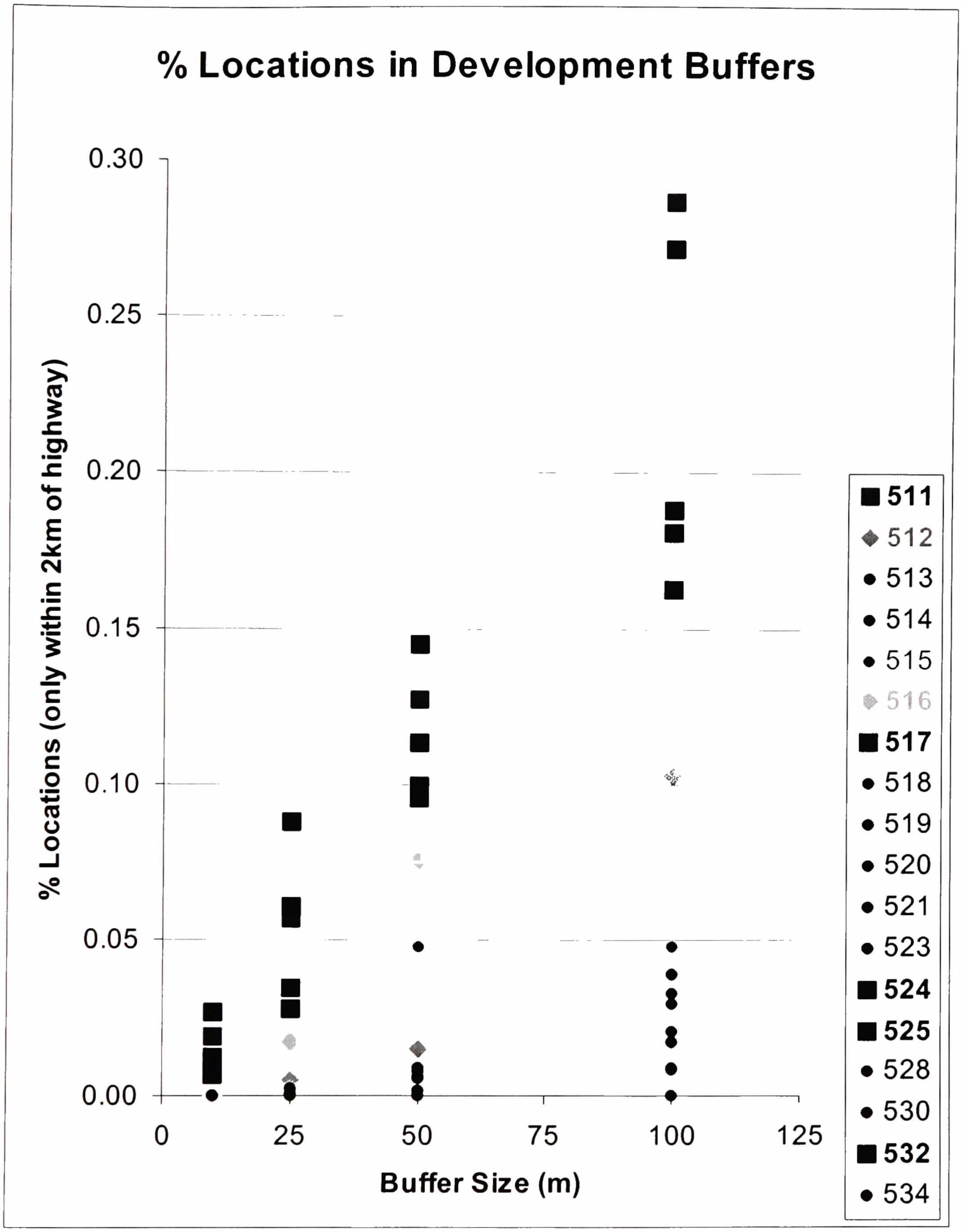

Figure 3.3. Percentage of black bear locations in 10 m, 25 m, 50 m, and 100 m buffers around development structures within 2 km of Highway 93. Bears classified as food-conditioned shown in bold with black squares, bears classified as habituated shown with grey diamonds, and nonhabituated bears are shown with black circles.

Tree Diagram Key: Record number) Bear ID

1)511	2)512	3)513	4)514	5)515	6)516
7)517	8)518	9)519	10)520	11)521	12)523
13)524	14)525	15)528	16)530	17)532	18)534

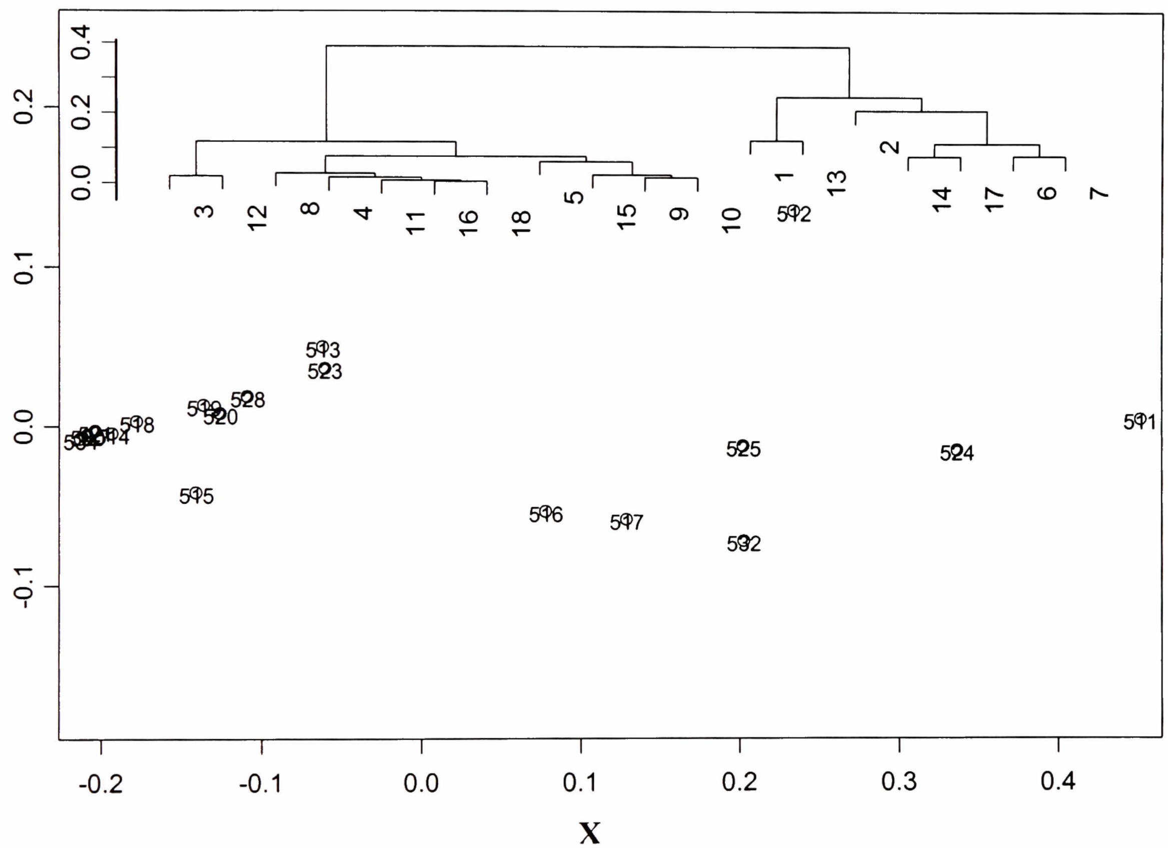

Figure 3.4. Cluster analysis and tree diagram were used to help identify food-conditioned, non food-conditioned, or habituated bears. Groupings are based on the percentage of black bear locations within 10 m, 25 m, 50 m, 100 m, and 200 m buffers of human development structures.

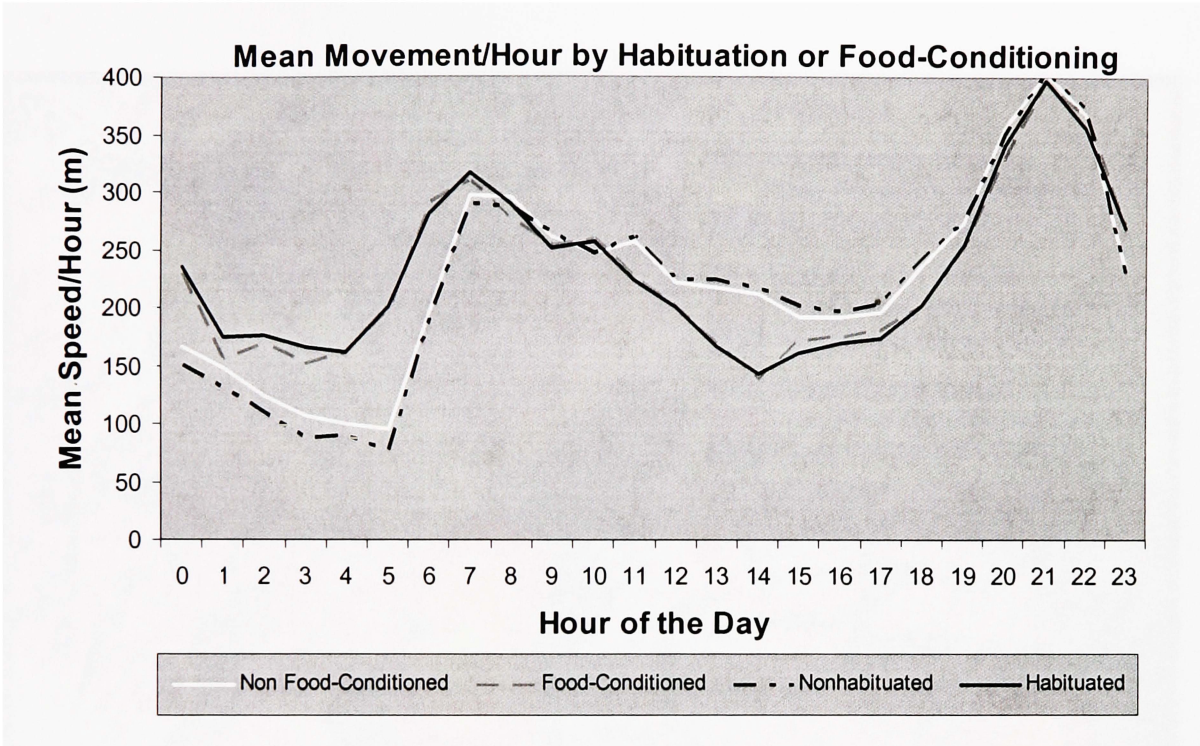

Figure 3.5. Movement rates of food-conditioned and habituated black bears versus non food-conditioned or nonhabituated black bears.

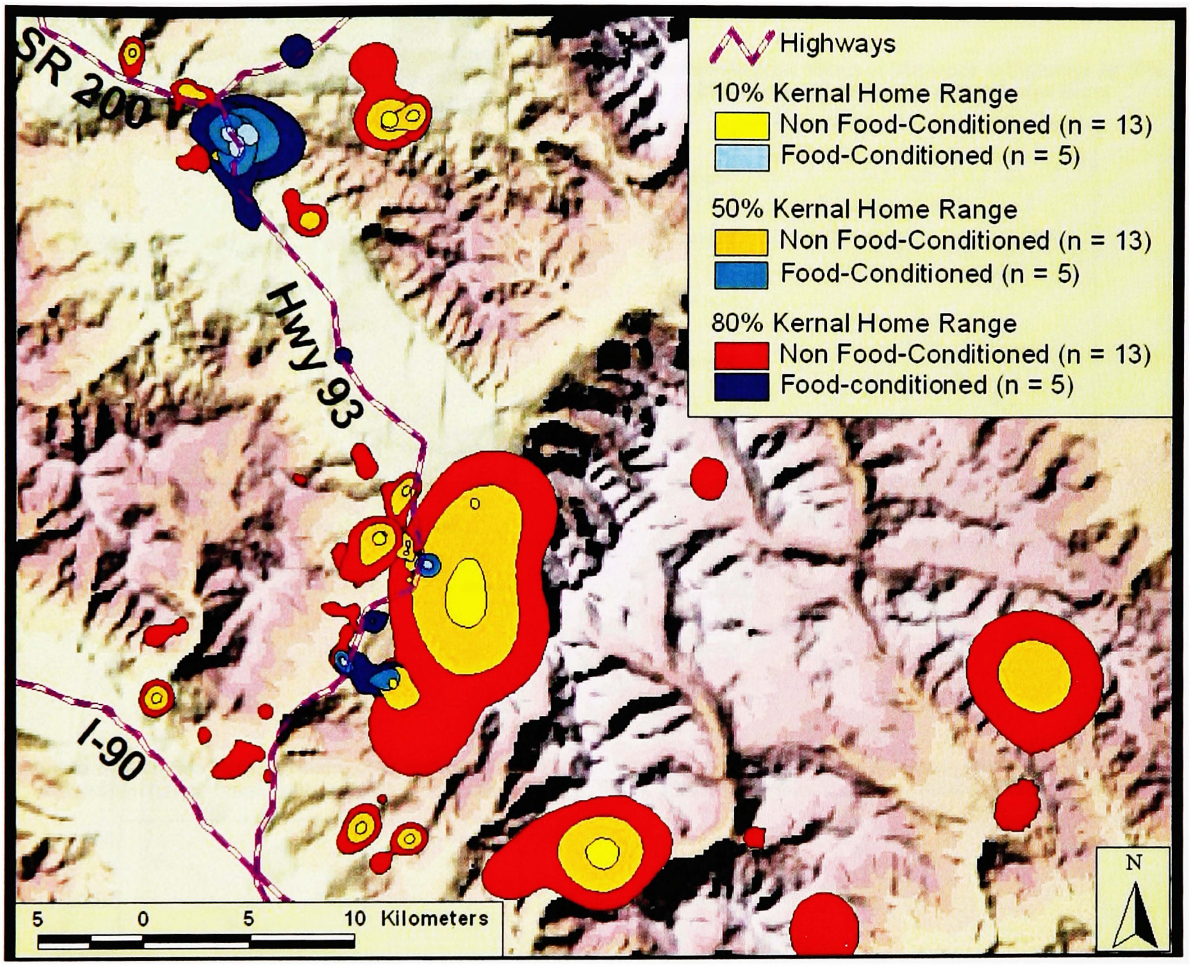

Figure 3.6. Location of kernel home ranges of black bears relative to highways on the Flathead Indian Reservation, located northwest of Missoula, MT.

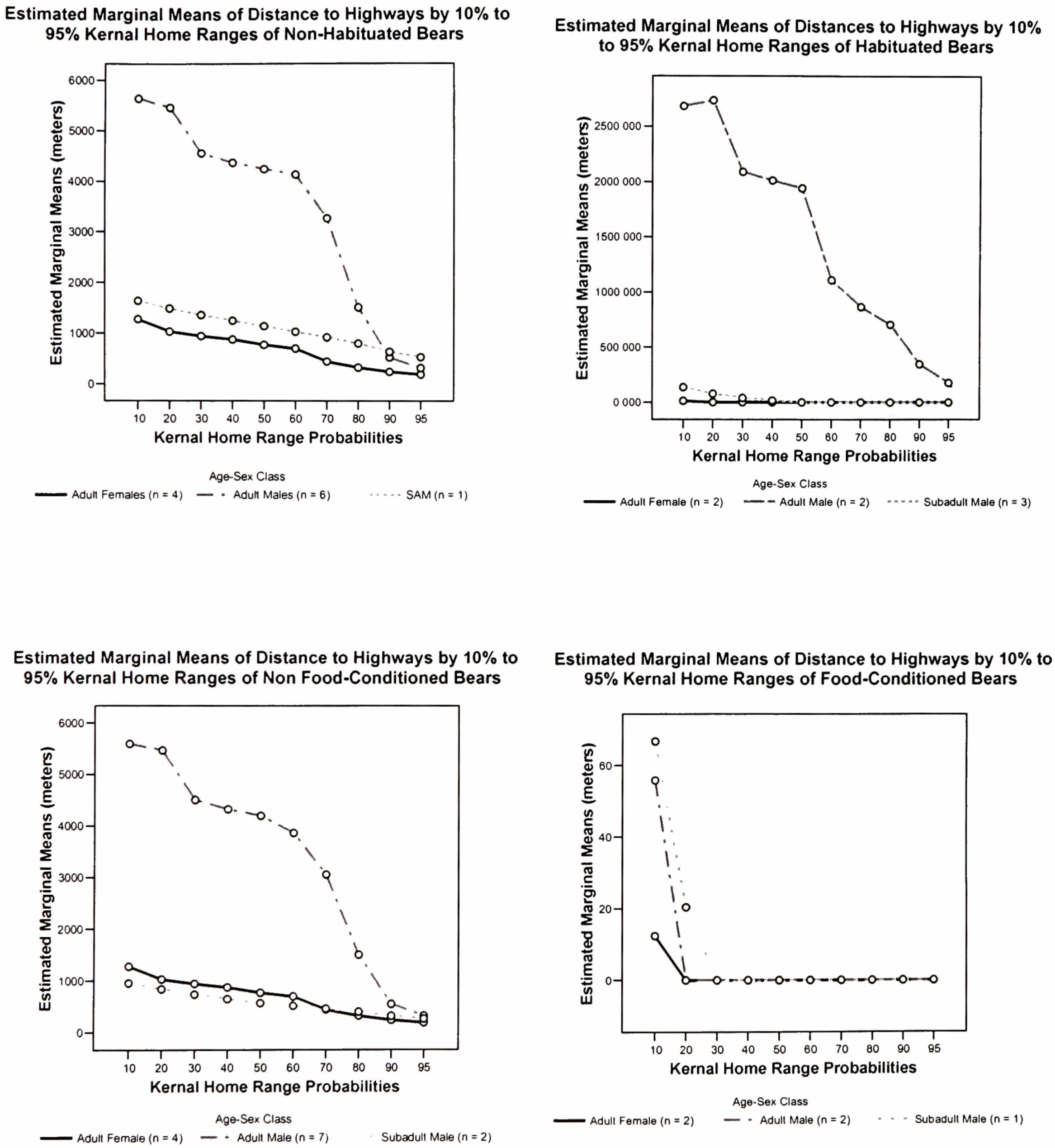

Figure 3.7. Trend of differences among age-sex classes with regard to kernel home range distance (m) to highways. Differences are shown for when bears (*n* = 18) are grouped as either a) habituated vs. nonhabituated or b) food-conditioned vs. non food-conditioned.

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APPENDIX A:

Genetic Tagging and Density Estimation of Black Bear Within the Highway 93 Transportation Corridor

ABSTRACT

I explored the utility of non-invasive DNA sampling as a tool to evaluate impacts of highway expansions on animal populations. I conducted DNA analysis of hair samples derived opportunistically from a variety of sources and from systematically distributed hair-collection stations to identify a minimum black bear (*Ursus americanus*) density within the Highway 93 corridor and establish a baseline of genetic variation for the resident black bear population. I identified 83 bears within the highway corridor, 48 of which were male and 35 were female. Genetic analyses revealed that heterozygosity was relatively high in this sample population, and that 4 bears crossed the highway at least once. My results indicated that the highway was permeable for at least some segment of the bear population, and that bears in this population did not appear to be suffering from low genetic variation. By archiving genetic samples prior to expansion projects, managers will be able to assess future changes in genetic diversity and gene flow across the highway.

INTRODUCTION

In the Northern Rockies, linkage between historically connected large blocks of habitat is considered vital for the persistence of large carnivores such as black bears (Servheen et al. 2001). Maintaining connectivity between small and isolated populations prevents detrimental consequences of habitat fragmentation. Immigrants can demographically bolster populations that have been reduced by negative environmental conditions or catastrophic events. Maintaining linkage between historically connected populations can also preserve gene flow, reducing the chances of inbreeding and lessening the negative effects that arise from genetic drift. Otherwise, the long-term genetic effects of complete population isolation could result in a reduction in the fitness of individuals due to the fixation of deleterious alleles (Land 1994).

Physical barriers to wildlife movement, such as transportation corridors, cause habitat fragmentation, pose risks for maintaining species diversity, and have negative demographic and genetic effects on many species (Mader 1984, Servheen and Sandstrom 1993, Forman and Alexander 1998, Forman and Deblinger 2000). Transportation corridors become less permeable as suitable habitat in the corridor decreases due to increases in human activity and development. As corridors become less permeable to a population, the frequency of movements along and across highway features decrease due to avoidance and mortality events related to crossing attempts (Brandenburg 1996, Romin and Bissonette 1996, Forman and Alexander 1998). Transportation corridors can therefore interrupt inter-population movement, which is vital for maintaining healthy meta-population dynamics (Hanski and Gilpin 1991).

Historically, the effects of highway permeability on local populations have been studied by directly measuring movement across the corridor through techniques such as collared animals, track beds, and cameras. More recently, researchers have employed new techniques involving non-invasive DNA sampling. Non-invasive DNA sampling using hair stations has been commonly used to estimate population size when coupled with mark-recapture analysis (Foran et al. 1997, Woods et al. 1999, Mowat and Strobeck 2000, Boulanger et al. 2002). Moreover, measures of genetic variation derived from this type of sampling can be used to estimate connectivity between fragmented areas (Marshall and Ritland 2002). As the effects of transportation and development on wide-ranging species has become a greater concern, it has been used to measure connectivity across barriers such as highway corridors by using genetic assignment tests (Proctor 2003) or geostatistics (Thompson et al. 2005). DNA sampling can facilitate the quantification of connectivity directly when genotyped individuals are recorded on both sides of a highway, and indirectly through measures of population-level genetic variation.

My objectives were to conduct non-invasive DNA sampling prior to highway design changes to calculate a minimum density of black bears within the highway corridor and archive DNA samples to establish baselines of genetic variation within the resident bear population. This information will allow future quantification of any changes in black bear density and gene flow due to highway design changes and increasing traffic and human developments within the highway corridor.

STUDY AREA

I analyzed black bear movement on and adjacent to the Flathead Indian Reservation, Montana, home to the Confederated Salish and Kootenai Tribes (CSKT). U. S. Highway 93 runs north-south through the Flathead Indian Reservation, and consists of four lanes up to the southern boundary of the Reservation at the town of Evaro, where it becomes a two-lane highway (Figure 1.1, Chapter I). This highway has recently started to incur a dramatic increase in traffic volumes and development. Annual mean daily traffic volumes on Highway 93 are 9008 (range 4610-13,154) vehicles/day in the Evaro area and 8062 (range 5231-11,534) vehicles/day in the Ravalli area south of Ravalli junction (Chapter II). The Montana Department of Transportation (MDOT) is widening most of Highway 93 between Evaro Hill and Polson to four lanes. This improvement will include placement of 42 wildlife crossing structures capable of providing passage across the highway to a variety of species as well as fencing to promote the use of structures. Details of the proposed design changes to the highway can be found in the highway improvement project Memorandum of Agreement (Montana Department of Transportation et al. 2000).

The study area is on the southwestern edge of the Northern Continental Divide Ecosystem (USFWS 1993), and encompasses Highway 93 from Evaro Hill to St. Ignatius, and the extent of State Route 200 in which research bear highway crossing activity occurred. The study area contains primary linkage habitat necessary to maintain connectivity between the Northern Continental Divide Ecosystem to the northeast and the Salmon-Selway Ecosystem to the southwest (Metz 1994, Servheen et al. 2001). The southern study area is characterized by almost continuous forest cover (77%) with few agricultural fields in the valley bottom, but the northern part is characterized by patchy forest cover (25%) intermixed with wide expanses of Paluse Praire and agricultural fields. The study area is largely within the boundaries of the Reservation, but is characterized by a mixture of private, tribal, federal, and state lands. Forest cover is predominantly coniferous, but deciduous environments are found along streams, irrigation ditches, and ponds, especially in the valley bottomlands. Bear foods include berries and non-native fruit trees, which are abundant in and adjacent to developed areas concentrated along the highway (Servheen 1983).

METHODS

DNA Genetic Sampling using Hair Collection Stations

Samples were collected during the summer 2003 field season. Bear hair was collected on both sides of the highway following methods adapted from Woods et al. (1999), involving placement of barbed wire in the form of a ring around 3-4 trees about 50cm above the ground. To increase capture probability, I used 2 wire rings, placed at 25 and 55 cm above ground level. In areas where cattle or cattle sign was present, sampling wires were fenced off with an additional 2 rings of wire, placed at thigh and chest height, to minimize disturbance by livestock and data loss by such non-target species. Hair collection stations remained in fixed locations and sampling occurred in 2 sessions. Stations were rebaited every 10-14 days, at which time hair samples were collected and stations were cleaned of hair by burning the barbs with a lighter. Hair collection stations were constructed and baited for Session 1 between 7 July and 16 July 2003. Session 1 samples were collected and sites were re-baited for Session 2 between 21 July and 30 July. Session 2 samples were collected and removed between 4 August and 13 August. Researchers collected all samples using tweezers and while using latex gloves to avoid human contamination of samples.

Sampling stations were placed in 2 sampling areas centered on the towns of Evaro in the southern part of my study area and Ravalli in the northern part of my study area (Figure 4.1). The sampling areas were 100 km^2 and contained 25 grid cells, 12 on the west side of the highway and 13 on the east side of the highway in Evaro, and 13 on the West side and 12 on the East side in Ravalli. Sampling was conducted using 2 km x 2 km grid cells, with one hair collection station deployed within each grid cell containing suitable sampling habitat. Suitable sampling habitat was defined as a minimum of 3 appropriately spaced trees that were not immediately adjacent to any residential development. If no suitable sampling habitat was available, the cell was not sampled. An effort was made to place sampling stations near the center of grid cells to maximize distance between stations and allow a more even coverage of the sampling areas. If a cell straddled the highway, the sampling station was constructed on the side of highway with the larger grid cell area.

Bears were lured over/under the wires and into the ring by pouring a non-rewarding scent lure on a pile of debris in the middle of the ring. Lure ingredients included fermented bison blood collected from rendering plants on the Flathead Indian Reservation, ground fish from a local Montana hatchery, and vegetable oil. This lure was made by USFWS personnel and allowed to ferment over 6 months to assure adequate potency. To bring bears in from a greater distance, I also hung 2 film canisters filled with lure from tree branches. Film canisters at each sampling site contained both shellfish and fermented egg essence in session 1, but were changed to skunk essence in session 2. By changing the lure between sessions I hoped to provide novel stimuli to the bears that would promote continued visitation of sampling stations. As the bears passed over, under, or between the wires, hairs were caught on the barbs. I used wire with 4-pronged barbs to maximize hair pulling capability. The "pulled" hair caught on the barbs contained a hair follicle, from which DNA was later extracted for genetic analysis.

During both 2002 and 2003, hair samples were also obtained through other research trapping and collaring efforts, from bear mortalities on the highway, from tribal management-trapped bears, and opportunistically when bear hair was encountered on fences and gates near research activity areas.

Analysis of DNA Samples

All hair samples were sent to a lab for extraction, analysis of heterozygosity, and genotyping. Lab protocol dictated that samples that appeared to contain DNA from more than one individual and samples that produced solid data for fewer than 3 loci were excluded from further analyses. Samples with initial incomplete genotypes that did not fall in either of these previously mentioned groups were re-evaluated and ultimately excluded from analysis if full genotypes were not established. All similar genotypes were scrutinized to prevent overestimation of the number of sampled individuals. Six microsatellite markers were evaluated for 60 samples to evaluate genetic variation. Markers were selected based on previous black bear research in nearby areas in the Swan and Yaak mountains. The observed heterozygosity of the 5 most variable markers was used to calculate average heterozygosity for the study area. Five microsatellite DNA markers plus a gender marker were used for genotyping and assessment of sex ratios (Wildlife Genetics International, Nelson, BC, Canada). I examined genotyped samples to identify the number of individuals captured more than once, the number of individuals captured during each DNA session or through other methodologies, the number of researchmarked bears captured though DNA sampling, and the geographic relationship of the samples within the study area.

RESULTS

A total of 22 stations were constructed in Evaro for Session 1 and maintained through Session 2. A total of 13 stations were constructed in Ravalli during Session 1 and an additional 2 stations were added during Session 2. Fewer stations were deployed in Ravalli due to either a lack of trees or lack of trees an inadequate distance from residences, or due to an inability to gain landowner permission. I therefore had a total of 72 sampling units over the two areas and two sessions, combined. At individual units, sample sizes ranged from just one hair on 1 barb to multiple hairs on over 50 barbs. Hair was collected from 92% of the 72 units, but because many hair samples were of questionable quality or species, sampling success was actually lower. Two hundred and thirty-two samples were analyzed (Table 4.1).

Twenty (9%) of the 232 samples could not be extracted. Of the samples that were extracted, 159 (75%) were successfully genotyped, 6 (3%) contained mixed DNA, and 47 (20%) did not produce enough data to establish complete genotypes (Table 4.2). Of the successfully genotyped samples, 63 were from DNA sampling session 1, 54 were from DNA sampling session 2, 24 were from bear capture operations during radio-collaring, 10 were from road mortalities, 2 were from tribal management action, and 6 were opportunistic (Table 4.3). Analysis of genotyping results indicate that between August of 2002 and November of 2003, I was able to identify 83 different black bears within the highway corridor as a result of all sampling methods (trapping, management, mortalities, and DNA sampling) combined. Of these 83 bears, 48 were male and 35 were female. A detailed breakdown of genotyped samples can be found in Tables 4.4 and 4.5. Four bears were identified at stations on both sides of the highway, indicating that Highway 93 was crossed by these bears. The genetic variability in this population was exceptional, with both observed and expected heterozygosity averaging over 85% when using the five most variable of the 6 markers evaluated (G10H = 0.94, , G10J = 0.82, MU59 = 0.74, G10P = 0.91, G10X = 0.82).

While the DNA data was capable of identifying crossing events by individual bears, the number of times these bears crossed or the level of habituation of these bears to human activity remained unknown. DNA sampling indicated that 4 of 83 black bears (5%) as having crossed the highway at least once. In contrast, collaring black bears with GPS collars provided precise crossing location data, indicated that 10 of 18 (56%) collared bears crossed the highway, and revealed that the 18 bears crossed a total of 212 times combined (Chapter II). However, if all bears, or their offspring, with highway crossing tendencies were eventually killed in vehicle collisions or through management removal, the populations could still become isolated. The high heterozygosity documented through the DNA sampling indicated that this is not the case.

DISCUSSION

I documented 69 bears within an area of 148 km^2 through the DNA sampling alone, and 83 bears within this same approximate area using all methods combined, which translates to a minimum density of 0.47 – 0.56 bears per km^2 (or 1.2 - 1.5 bears per square mile) within approximately 4 km of Highway 93, although fewer hair collection stations were available in the Ravalli sampling area (Figure 4.1). It should be noted that this density estimate is simply the number of identified individual bears divided by the area of the DNA sampling grid, and does not take into account issues such as closure as well as probability of capture. However, this minimum density estimate is similar to estimates by Kasworm and Manley (1990), who reported an estimate of 0.50 bears per km^2 for the Cabinet Mountains in Northwestern Montana. In contrast, this density is greater than that of most hunting districts (HDs) or block management units (BMUs) sampled by Montana Fish, Wildlife, and Parks (HD 100 = 0.20/ km^2, BMU 411 = 0.12/km2, HD 292 = 0.13/ km^2, HD 130 = 0.50/km^2) between 2002-2004 (R. Mace, personal communication). The high level of heterozygosity of this population in conjunction with the existence of crossing activity is consistent with the notion that this highway is not currently functioning as a barrier to gene flow.

TABLES

Table 4.1 Summary of the number and origin of DNA hair samples sent in for analysis from genetic tagging efforts of black bear within the Highway 93 transportation corridor northwest of Missoula, MT.

Sample Origin	# of Stations/Locations	# Samples Sent for Analysis
DNA Session 1	31	86
DNA Session 2	34	96
Research-Trapped Bears	11	24
Bear Highway Mortalities	14	14
Management-Trapped Bears	2	2
Other Opportunistic	5	10
TOTAL	**85**	**232**

Table 4.2. Summary of DNA sample extraction results from genetic tagging of black bear within the Highway 93 transportation corridor northwest of Missoula, MT.

# Samples Submitted	**232**
# Not Extracted	20
# Failed	47
# Mixed Results	6
# Successful	**159**
Success Rate (# Extracted / # Successful)	**75%**

Table 4.3. Origin of successfully genotyped DNA samples from black bear within the Highway 93 corridor northwest of Missoula, MT.

# From DNA Hair Snare Session 1	63
# From DNA Hair Snare Session 2	54
# From Trapping	24
# From Roadkills	10
# From Tribal Management Action	2
# From Opportunistic Collection	6
Total Successful Samples	**159**

Table 4.4. Breakdown of the origin of genotyped samples from black bear within the Highway 93 transportation corridor northwest of Missoula, MT.

Category	#	Notes
# males	48	
# females	35	
# individual genotypes	**83**	**156 km2**
# of bears captured DNA session 1	32	
# of bears captured DNA session 2	37	
# of bears caught at the 2 extra stations sampled in session 2	1	#567 (only time caught)
# of bears captured both session1 and 2	32	
# of bears caught session 1 only	16	140 km2 (35 stations)
# of bears caught session 2 only	21	148 km2 (37 stations)
# of bears captured with DNA sampling	**69**	**148 km2 (37 stations)**
# of GPS collared bears captured session 1 only	0	
# of GPS collared bears captured session 2 only	1	(516)
# of GPS collared bears captured both sessions	2	(518, 530)
# of GPS collared bears captured with DNA sampling	**3**	
# of trapped but uncollared bears captured session 1 only	1	(527)
# trapped but uncollared bears captured session 2 only	1	(522)
# trapped but uncollared bears captured both session	0	
# trapped but uncollared bears captured	**2**	
# of roadkilled bears captured session 1 only	1	RK013
# of roadkilled bears captured session 2 only	0	
# of roadkilled bears captured both sessions	1	RK015
# of roadkilled bears captured	**2**	

Table 4.5. Summary of capture frequency and capture locations from black bear genetic tagging efforts along the Highway 93 transportation corridor northwest of Missoula, MT.

Group	**# bears (bear ID, or sample ID if bear unknown)**
# of bears with >1 sample	112
Bears with 4 locations	1
Bears with 3 locations	9 (B518*, B527, B528, B530, RK013**,RK015)
Bears with 2 locations	10 (B516, B517, B522, B533)
Bears with 1 location	63
# of bears on Eastside	46 (including both-side bears)
# of bears on Westside	32 (including both-side bears)
# of bears on Both sides	4 (Bear Id 522, Bear Id 533, 049, 112)
#of bears on highway (roadkills)	9
# on highway + westside location	0
# on highway + eastside location	2 (037 (RK013), 039 (RK015)

*** B = Research bear** ****RK = Roadkilled bear**

FIGURES

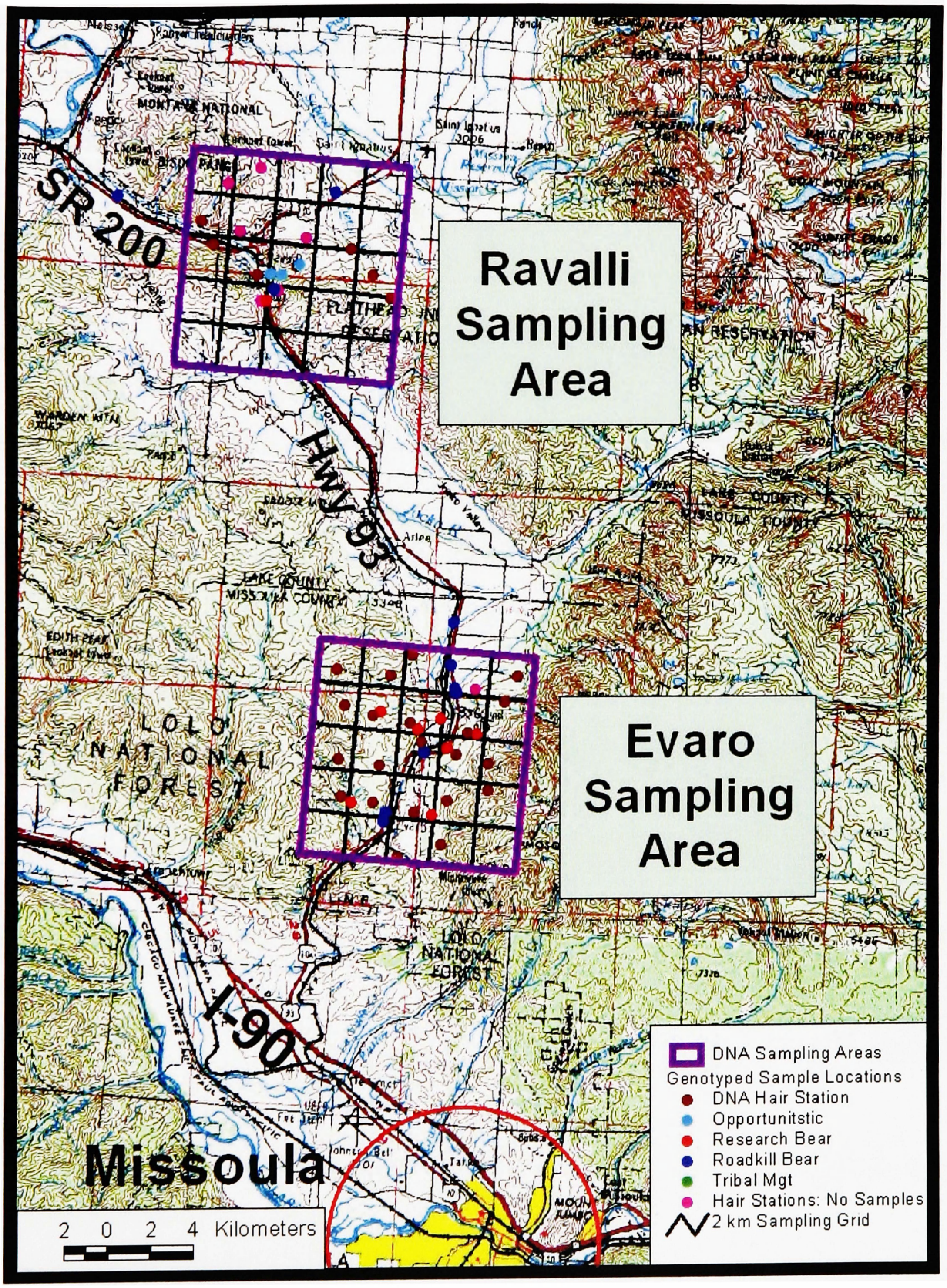

Figure 4.1. Map of DNA sampling areas and hair collection locations on the Flathead Indian Reservation, northwest of Missoula, MT.

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